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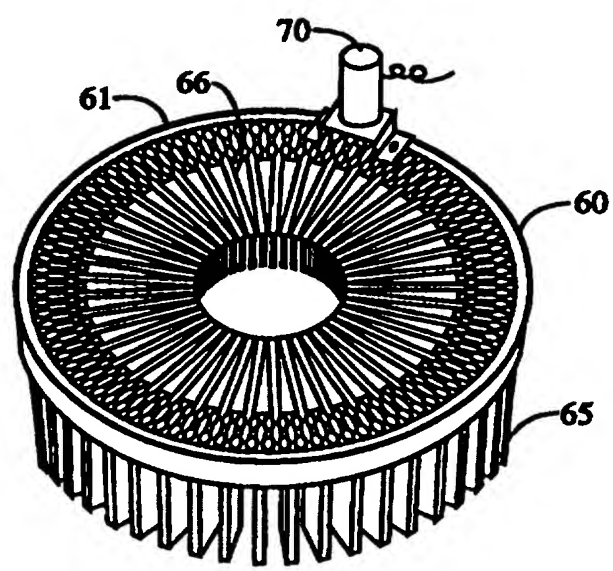
(57) Abstract

A series of closely packed thermocouples formed into a torus (60) are held in compression against the Lorentz Force by a dielectrically insulated tie strap (61). High current circulates through the torus (60) due to reduced electrical path length effected by low-thermal-conductivity elements (64) and grooves (38) formed in hot and cold fins (66 and 65). Reduced heat transfer between hot and cold fins (66 and 65) generates higher circulating current. Thermoelectric junctions formed between the hot and cold fins (66 and 65) and the low-thermal-conductivity elements (64) are preferably established by coated layer(s) (67) of dissimilar materials including bismuth, constantan, nickel, selenium, tellurium, silicon, germanium, antimony, nichrome, iron, cadmium, tungsten, gold, copper, zinc, and silver. Operating as a thermoelectric generator (40), electrical power may be drawn from the circulating electric current using either a vibrating mechanical switch (70), a Hall effect generator (140) or a Colpits oscillator (159).



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IMPROVED THERMOELECTRIC UNIT WITH ELECTRIC INPUT/OUTPUT PROVISION

Technical Field

The present invention relates to thermoelectric generation and refrigeration units, and in particular to a thermoelectric generator and/or refrigerator which utilizes a torus made up of close-coupled thermocouples that cause a very high electric current to circulate through the torus induced by maximizing a temperature differential across thermoelectric elements, and utilizing low electrical resistance together with high Seebeck effect thermoelectric junctions.

Background Art

The quest for a reliable, silent, energy converter with no moving parts that transforms heat to electrical power has led engineers to reconsider a set of phenomena called thermoelectric effects. These effects, known for over a hundred years, have permitted the development of small, self contained electrical power sources, but too small to find practical application for home or commercial power generation.

A normal electrical switch generally uses only the same type metals where no effort is made to heat and cool any of the elements, and no thermoelectric voltage results from a difference between switch elements. Electrical resistivity in a conventional switch causes a voltage drop when an electrical current flows through the switch, and constitutes a resistive load on the electrical current circulating through the electrically closed circuit established by the switch's closing.

Thermoelectric generation and refrigeration, based on the Seebeck effect, is the physical phenomenon in which a thermocouple, formed by juxtapositions of two dissimilar materials that are usually metals or alloys of metals, is used for temperature measurement. As is well known, a thermocouple having its pair of junctions maintained at different temperatures produces a voltage difference that measures a specific temperature difference between the two junctions. An imposed temperature difference will result in a voltage across the thermocouple or a

current flowing in a loop through the thermocouple, that constitutes electrical power generation on a small scale. This aspect of thermoelectric generation is widely utilized in deep-space applications, for example, on the Voyager I and II satellites, which were launched in 1977 and are still sending back pictures today, almost 20 years later. In such applications of thermoelectric power generation, a radioactive material provides heat for the thermoelectric generators, and thus provides a long-lived energy supply. Similar thermoelectric power generation units will also be used in the upcoming Cassini mission to Saturn. The advantages of thermoelectric solid-state energy conversion include compactness, lighter weight, silent operation and trouble-free power generation over a long lifetime.

Thermoelectric generation and refrigeration has been around for over a hundred years, first discovered by Seebeck in 1822. There have been numerous improvements and analysis of Seebeck's work and many patents have issued based on improvements to this early discovery. Most of this work has been directed toward finding metal combinations or alloys that produce the highest Seebeck junction voltage, for series connected thermocouples or thermoelectric elements, to produce a high voltage for supplying current to power an electrical load.

Most thermoelectric generators use a set of series connected junctions for producing an electric current for driving an electrical load. Typically, materials with high Seebeck voltage also have high electrical resistivity that tends to reduce electrical current flowing in the circuit. Previous thermoelectric generators and refrigerators use alloys to produce high Seebeck voltage for identical thermocouple temperature differences. Alloys typically have several times higher Seebeck voltages, but are found to have resistivities that are typically ten times higher than any of the commercially pure metals (99%) making up the alloys. If an electrical circuit contains only a series of thermoelectric elements that produce the electrical current flowing through the circuit, higher resistivity in any of the thermoelectric elements drastically reduces the amount of current flowing through the circuit.

The structure of the present invention differs in various ways from that disclosed in United States patent nos. 4,859,250 and 5,022,928 that issued on applications filed by Buist, 2,919,553 and 3,326,727 that issued on applications filed by Fritts, 3,119,739 that issued on an application filed by Von Koch, 3,090,875 that issued on an application filed by Harkness, 2,864,879 that issued on an application filed by Toulmin, 2,425,647 that issued on an application filed by Salver, and 2,415,005 that issued on an application filed by Findley, as well as the following patents that have issued in the name of the inventor of the present application.:

4,997,047 High Speed Electromagnetically Accelerated Earth Drill;

5,024,137 Fuel Assisted Electromagnetic Launcher;

5,168,118 Method for Electromagnetic Acceleration of an Object;

5,168,939 Oil Well Drill;

5,393,350 Thermoelectric Generator and Magnetic Energy Storage Unit; and

5,597,976 A Thermoelectric Generator and Magnetic Energy Storage Unit with Controllable Electric Output.

Disclosure of Invention

An object of this invention is to maximize the production of electrical power from a thermoelectric generator and make a practical converter that can produce an alternating voltage and current that can be used to directly power household and industrial loads without the aid of the utility grid.

Another object of the present invention is to maximize the current circulating in a torus of thermoelectric junctions, and thereby maximize the energy stored in a strong magnetic field. Maximizing the circulating current is effected by:

1. reducing the internal electrical resistance in the torus;
2. choosing materials for the thermoelectric junctions forming the torus so as to produce the highest current, consistent with low internal electrical resistance; and

3. minimizing heat flowing between heating and cooling fins thereby maintaining individual junctions at the highest temperature differentials, and likewise highest Seebeck drive voltage.

In particular, the thermoelectric unit uses materials for thermoelectric junctions that generate voltages arranged to alternate in sign of the Seebeck voltage, referred to herein as p-type and n-type material systems, and that have both high Seebeck voltage and high electrical conductivity (low electrical resistance).

One more object of the present invention is to produce high-energy electrical output power in the 0 to 240 Volt range of either an alternating current ("AC") or direct current ("DC") by perturbing the circulating current in the torus

An additional object of the present invention is to provide a novel way to realize improved electrical conductivity and high Seebeck voltage for p-type and n-type thermoelectric elements by using high electrical and thermal conductivity copper or silver core, coated with thin layers of thermoelectric material. The preceding structure for the thermoelectric elements yields thermoelectric junctions that operate both as a high-Seebeck voltage, high electrical conductivity generator thereby creating higher circulating electric current in the torus and higher power output from a thermoelectric generator for the same temperature differential and heat flow.

An added object of the present invention is to use threaded junctions between the thermoelectric elements and hot and cold fins so the thermoelectric elements function as thermal resistors to reduce heat flow between the hot and cold fins to thereby increase temperature differentials across the thermoelectric junctions, and to increase the overall thermal-to-electric efficiency of the thermoelectric unit.

An alternative object of the present invention is to use thermoelectric elements formed by coating a threaded copper core with a dissimilar metal that has a complementary high Seebeck voltage so the high electrical-conductivity thermoelectric elements also produce a high thermoelectric junction voltage.

Yet another object of the present invention is to reduce electrical resistance across fins by grooving the hot and cold fins on both sides to receive the thermoelectric elements, the thermoelectric elements fitting into the contour of the groove thereby reducing the length between thermoelectric elements from one side of the hot or cold fin to the other side.

A contributory object of the present invention is to partially flatten the threaded rods into an oval shape, including the threads, so as to preserve threads on the threaded rod while concurrently reducing the material distance and electrical resistance between alternating hot and cold junctions.

An ancillary object of the present invention is to use thin coatings of metal to serve as ohmic braze connectors for threaded tips of the thermoelectric elements to the hot and cold metal fins because interconnections and junctions made of plated metal layers do not exhibit less resistance than alloy thermoelectric junctions.

An associated object of the present invention is to use plated layers to provide a corrosion and oxidation resistant protective barrier on the hot and cold fins and thermoelectric elements, such as by plating of hot fins with platinum or palladium in the regions where flame and hot gas impinges to also serve as a catalytic converter for exhaust gasses used in heating a thermoelectric generator, thereby reducing pollution, while preventing oxidation of the heated fins.

Another corollary object of the present invention is to use a plated layer or layers to form metallic planar junctions that improve the lifetime of the thermoelectric junctions, sealing them from the environment and maintaining the high Seebeck voltage characteristics of the junctions over the lifetime of the device.

Another object of the present invention is to provide a thermoelectric unit that employs low-thermal-conductivity thermoelectric elements which are formed as two halves that abut each other along an electrically-conductive, low-thermal-conductivity longitudinal surface, the low-thermal-conductivity thermoelectric elements thus formed are received into grooves formed in the thermoelectric unit's hot and cold fins.

Still another object of the present invention is to use a special tie strap that encircles the thermoelectric unit to contain the Lorentz Force that builds up in the torus, the tie strap secured around the torroidal current storage loop to maintain a prestress on the thermoelectric junctions,.

Another object of the present invention is to use a tie strap for encircling the thermoelectric unit that includes an insulating gap in the strap that de-couples the strap as a secondary winding.

A related object of the present invention is to interpose springs between the torroid formed by hot and cold fins and the tie strap to maintain the necessary prestress to overcome the Lorentz Force despite contraction and expansion of the coil due to temperature changes.

A subsequent object of the present invention is to construct a novel black box around the hot fins to reradiate infrared heat back to the hot fins to improve the efficiency of the chamber for heating the hot fins, thereby raising the temperature of the hot fins, increasing the temperature differential across the thermoelectric junctions, increasing the magnitude of the current circulating in the torus, increasing the electrical power output efficiency of the thermoelectric unit as a thermoelectric generator, and all this for the same amount of fuel.

A successive object of the present invention is to use a fluid, such as air, water, or other liquid to draw heat away from the cool elements of the thermoelectric generator and then be able to use the fluid in a heat pump, radiator or other device for drawing the heat out of the fluid to cool it before recirculating the fluid through the thermoelectric unit.

A further object of the present invention is to utilize a low power, magnetically activated, vibrating power output switch comprised of a longitudinally vibrating threaded armature that is driven in one direction by the mechanical action of a solenoid and in the opposite direction by a spring. The armature is disposed in a larger threaded hole formed between a pair of immediately adjacent fins, both the armature and the hole being threaded with the same pitch. The threaded armature and hole forming an on/off switch for opening and closing a loop for an

electric current circulating through the torus so that when the threads of the armature and the hole contact in both an up and down position, the electric current flows through the torus, and when not in contact, then interruption of current flow in the torus produces an electrical output that is useful for driving an electrical load, the switch thus operating as a low power input, high power output device.

A different object of the present invention is to provide a mechanical input to activate the solenoid of the vibrating switch used in generating electrical power with the thermoelectric unit by either using a finger operated mechanical method where a one-way spring powered pendulum forces the solenoid to vibrate a number of cycles until the electrical output of the thermoelectric unit can self power a sinewave generator powering the vibrating, voltage producing, current interrupting switch . Alternatively, a finger operated piezoelectric generator may first provide a spark for igniting a burner. After the thermoelectric unit reaches operating temperature, the piezoelectric generator is then used for storing sufficient electrical energy to power the sinewave generator for driving the solenoid until the power output of the thermoelectric generator can drive an external electrical load.

Another alternative object is to provide a novel way to draw electrical energy from the current circulating through the torus without opening the torus by interposing a Hall-Effect switch between a pair of immediately adjacent fins of one of the thermoelectric junctions in the torus, and by controlling an externally applied magnetic field oriented perpendicularly to the electric current circulating through the torus. Upon application of the external magnetic field, a voltage appears across of the torus that is proportional to magnetic field strength and to the circulating current, and power can be drawn from the thermoelectric unit in the form of AC or DC depending on the characteristics of the external magnetic field. Electrical power generated in this way can be used to operate an electrical load without breaking the circulating current flowing through the torus, and without vibration or noise.

An extra object of the present invention is to control the voltage produced by a thermoelectric unit by controlling the flow of fuel supplied to a burner that produces heat for a thermoelectric generator.

Once again another object of the present invention is to provide a thermoelectric generator which burns methane, propane or butane gas from tanks mounted externally to the thermoelectric unit.

A separate object of the present invention is to provide a thermoelectric generator which can burn any type of fuel by providing a ventilated fuel burning area below the hot fins with an exhaust opening above.

A next object of the present invention is to provide an auxiliary grill on top of the thermoelectric generator above the heat exhaust opening to receive pots and pans for use in cooking.

The thermoelectric unit of the present invention builds magnetic field by circulating high current through a series of thermocouples preferably arranged to form a torus.. Electrical power may be drawn from this thermoelectric unit by supplying heat to hot fins, cooling cool fins, and perturbing the circulating current in the loop. Electrical energy produced in this way may be a high-voltage, high-energy AC or DC output. Generator efficiency depends on using alternating p-type and n-type material systems for the thermoelectric junctions that have both a complementary high Seebeck voltage, high electrical conductivity (low electrical resistance), and comparatively low thermal conductivity between immediately adjacent pairs of hot and cold fins..

The voltage that drives current through the torus is the sum of thermoelectric voltages around the series connected (electrically shorted) loop forming the thermoelectric unit's torus. The thermoelectric unit's capability for providing electrical power can be determined by multiplying the thermoelectric junction voltage by the number of junctions times the current circulating through the torus. The loop-shape of the torus operates as the primary of a transformer, with energy stored in the magnetic field generated by the circulating electric current. Appropri-

ately perturbing the circulating electric current produces a voltage for supplying electrical power to an external load.

Alternative structures provide a comparatively low thermal conductivity between immediately adjacent pairs of hot and cold fins while concurrently providing high electrical conductivity (low resistance). In one embodiment of these low-thermal-conductivity elements, short segments of threaded rod juxtaposed with and disposed between hot and cold fins reduce heat flow, and thereby correspondingly increases temperature differentials, and increases the overall thermal-to-electric efficiency of the thermoelectric unit when used as an electrical generator. To improve thermoelectric conversion efficiency of the unit for electrical power production the tips of the threads connecting the hot and cold fins are appropriately coated with materials that provide a complementary high Seebeck voltage which serve as emitters and collectors of electrons. Thermoelectric junctions made in this way act as thermal resistors with planned thermal gradients operating radially along the wedge-shaped edges of the threaded rod to greatly reduce heat flow through the thermoelectric junctions while maintaining high temperature differentials at the interface between thread tips and hot and cold fins. This structure for the thermoelectric junctions increases the thermal-to-electrical conversion efficiency by a factor of ten in electrical power performance over that of solid, dissimilar metal blocks mated to form thermoelectric junctions for the production of electrical power. By adding the thermal resistance between hot and cold fins, the amount of heat required to generate a pre-specified electric current circulating through the torus decreases by 80%. Incorporating these coated threaded rods for forming thermoelectric junctions between hot and cold fins raises thermal-to-electrical conversion efficiency from 4% to 12%. The improved heat management of this thermoelectric unit provides higher power capacity generator/output devices using the same amount of heat (fuel) and weight (mass) for the thermoelectric unit.

To further increase electrical conductivity in the torus (reduce resistance) grooves are formed into the hot fins as well as the cold fins so as to reduce the distance traveled by current

circulating through the torus. Upon assembling the torus, the grooves in the hot and cold fins receive the low-thermal-conductivity elements such as the threaded rod elements described above. Removing one-half of the copper path length by grooving the hot and cold fins reduces the resistance due to copper path length from 1.72×10^{-6} Ohm ("Ω") to 8.6×10^{-7} Ω for an L/A of 1 which doubles the amount of electrical current circulating through the torus for only a few percent decrease in temperature difference across the low-thermal-conductive thermoelectric junction elements.

Partially flattening the threaded rods into an oval shape reduces L in ρ L/A and further increases the electrical current circulating through the torus. A special die set for flattening the threaded rods includes threads so as to preserve threads on the threaded rod body during flattening. The partial flattening of the threaded rod reduces the length within thermoelectric elements around the loop from thread-tip contacts with hot fin on one side of the partially flattened threaded rod to the other side where the threaded rod contacts a cold fin. Partially flattening of the threaded rods reduces the material distance and electrical resistance between alternating hot and cold junctions.

Interconnections and junctions formed from material plated onto the low-thermal-conductivity elements do not exhibit high electrical resistivity that occurs for alloy thermoelectric junctions. Therefore, a torroidal-shaped thermoelectric unit can be assembled by applying thin coatings of plated metal for forming ohmic braze connections between threaded tips of rods and the hot and cold metal fins forming the torus. Plated layers can also be used advantageously for forming a protective barrier for corrosion and oxidation of hot and cold fins, and for the low-thermal-conductivity thermoelectric elements. Plating of hot fins with platinum or palladium in the regions where flame and hot gas impinges serves as a catalytic converter for exhaust gasses generated when using the thermoelectric unit as a thermoelectric generator. This has the effect of reducing pollution while preventing oxidation of the hot fins if the thermoelectric unit is used for producing electricity. Reducing pollution is especially important if thermoelectric generators

are fitted to internal combustion engines to heat from the internal combustion engine's exhaust. Such plated layer or layers can be used in this invention to form metallic planar junctions analogous to silicon planar junctions in semiconductor devices, improving the lifetime of the junctions, sealing them from the environment, and maintaining the high Seebeck voltage characteristics of the junctions over the lifetime of the device.

Improved elements decrease resistance from 10^{-6} to 10^{-7} Ω and double the Seebeck voltage for each set of thermoelectric junctions. Materials selected for complementary high Seebeck voltage is plated onto oxygen-free, partially flattened threaded copper rods. These low-thermal-conductivity elements have threaded cross sections to reduce heat flow, increase temperature differentials, and increase overall thermal-to-electric efficiency of the generator.

An alternative structure for the low-thermal-conductivity elements interposed between immediately adjacent hot and cold fins is a pin that fits into the grooves formed in the hot and cold fins. These pin are formed as two halves that abut each other along an electrically-conductive, low-thermal-conductivity longitudinal surface that is oriented between the hot and cold fins. Each low-thermal-conductivity element may be coated with a layer of material that provides a complementary high Seebeck voltage for the thermocouples. Such materials may be selected from a group consisting of bismuth, constantan, nickel, selenium, tellurium, silicon, germanium, antimony, nichrome, iron, cadmium, tungsten, gold, copper, zinc, and silver with bismuth and antimony being the preferred materials to respectively provide p-type and n-type junctions. The layer coating the low-thermal-conductivity elements may be overcoated with an electrically-conductive layer such as copper. Instead of or in addition to coating the low-thermal-conductivity elements with a complementary high Seebeck voltage material for forming the thermoelectric junctions, the grooves in the fins may be coated with that material. The groove on the first side of each fin is coated with a layer of material that provides one type of junction while the groove on the opposite side of each fin is coated with a material that provides the other type of junction. The fins are

then arranged so the same material forms the layer coating grooves that receive the same low-thermal-conductivity element. The same materials may be used for coating the grooves as are used for coating the low-thermal-conductivity elements, and the material coating the grooves may also be overcoated with an electrically conductive material.

A special tie strap encircles the thermoelectric generator to contain the Lorentz Force that results from the electric current circulating through the torus. When current flows in a ring, the current exerts a force on itself and this force is called Lorentz Force. The force is radial in nature and can be described by the formula: $F = q(E + v \times B)$. The tie strap is placed on the torus to maintain a prestress on the electrical junction connections between the fins and the low-thermal-conductivity elements. A tie strap is used to maintain a prestress to offset the Lorentz pressure from the large circulating current. The tie strap includes an insulating gap to de-couple the strap from becoming a secondary winding of a transformer with the current loop acting as the transformer's primary winding if electrical energy is removed from the electric current circulating through the torroidal-shaped thermoelectric unit. Coil springs interposed between the tie strap and the hot and cold fins enables the tie strap to maintain the necessary stress to overcome the Lorentz Force despite contraction and expansion of the torus due to temperature changes.

To improve the efficiency of a chamber for heating the hot fins if the thermoelectric unit is used as an electrical power generator, a novel black box is constructed around the hot fins to reradiate the infrared heat back to the fins. In working with flame heaters, it has been found that a significant portion of the heat that a catalytic burner produces is in the form of infrared radiation. Such infrared radiation travels past the hot fins to be wasted in the exhaust. The black-box arrangement sends a portion of this infrared radiation back across the hot fins thereby raising the temperature of the hot fins, increasing the temperature differential of the thermoelectric junctions, increasing the magnitude of the current in the loop, increasing the potential electrical power output of the electric generator

and all this for the same amount of fuel burned in the combustion chamber.

Two embodiments of the thermoelectric unit operating as an electric generator use liquid cooling as a heat sink for the cold fins. In an open trough version, all cold fins are immersed in a trough of water that evaporates as it absorbs enough heat from the thermoelectric cold junctions to boil the water. A closed manifold embodiment uses liquid to cool the cold fins of the thermoelectric unit either by passing water or a coolant liquid through the cold fins once and then exhausting the coolant, or recirculating the water or coolant through a radiator for cooling the liquid, and then recirculating the fluid through the thermoelectric unit on a closed and continuous basis.

Another embodiment of the thermoelectric unit operating as an electric generator is air cooled. An air blower, powered by a small portion of the electrical energy produced by the thermoelectric generator, blows air across the cold fins to draw heat from the thermoelectric junctions, and transfer it into the air stream for waste to the ambient or used in a heat pump or other system.

The large electrical current circulating in the torus permits drawing electrical power from the thermoelectric unit by collapsing the magnetic field produced by the circulating electrical. Operating as an electrical generator, power may be drawn from the thermoelectric unit in various different ways. One simple way of drawing electrical power employs a longitudinally vibrating threaded armature that is located within a larger diameter and threaded hole formed between an immediately adjacent pair of fins. The vibrating armature is driven in one direction by the mechanical action of a solenoid and in the opposite direction by a spring. Operating in this way, the threaded armature and hole form an on/off switch that opens and closes the loop for the electric current circulating through the torus. When the threads of the armature and the hole contact in both an up and down position, the electric current flows through the torus. And when the armature and threaded hole are not in contact, the interruption of current flow around the torus produces an electrical output that is useful for driving an

external electrical load. It is advantageous if hot and cold fins made from similar materials and separated by ceramic spacers provide the threaded hole while the armature is made from a material that differs thermoelectrically from the hot and cold fins. In this way longitudinal movement of the armature produces a Seebeck voltage when the metallic armature contacts the dissimilar material of the hot and cold fins.

An electrical solenoid excites mechanically the vibrating, voltage producing switch. The solenoid is powered by a sinewave generator that receives power from the thermoelectric generator after it begins operating. The switch vibrates longitudinally at one-half the frequency of the output voltage that is induced by collapse of the magnetic field. To start the vibrating action of the solenoid without the use of a battery, two methods have been invented; 1), a finger operated mechanical method where a one-way spring powered pendulum is used to force the solenoid to vibrate a number of cycles until the electrical output of the generator can self power the sinewave generator , and 2), a finger operated piezoelectric method of first storing electrical energy to power the sinewave generator. The finger, spring and the mass of the pendulum mechanically cause the solenoid, and likewise the vibrating switch to operate several cycles to make the thermoelectric generator self-starting by mechanical means without the use of an onboard battery. The oscillating pendulum comes to rest away from the electrically operated armature and stands at the ready for another manual start or flick of the finger when needed. The finger operated piezoelectric generator can also serve to ignite a burner of the thermoelectric generator by incorporating the push-button piezoelectric device into the electrical circuit. The piezoelectric generator can supply enough power to force the solenoid to vibrate a number of cycles until the electrical output of the thermoelectric generator produces sufficient power to operate the vibrating switch.

An alternate way to draw electrical energy from the current circulating ia a Hall-Effect device. A magnetic field, applied perpendicular to current flowing in a fixed conductor, causes a voltage across the conductor, perpendicular to the current and perpendicular to the applied external magnetic field. The

voltage generated in this way is referred to as the Hall voltage. Should the magnetic field change polarity (or be sinusoidal in nature), the Hall voltage will also be sinusoidal, producing AC. By placing contacts (connections) across a segment of one of the thermoelectric junctions in the ring, and by controlling the externally applied magnetic field, a voltage appears across the contacts, that is proportional to magnetic field strength and circulating current. Electrical power can be drawn from the generator ring in the form of AC or DC depending on the characteristic of the external magnetic field. Electrical energy can be withdrawn without interrupting current flow in the ring. Low voltage input to the external magnetic circuit causes high voltage output from the generator, and this can be used to operate an electrical load. No opening switch is required, there is no vibration or noise.

When a magnetic field of one Tesla is applied across a special thermoelectric segment in the thermoelectric unit conducting 50,000 amps, a Hall voltage of 1600 volts appears across the segment. Adjusting the applied magnetic field strength permits controlling the output voltage, and the applied field's frequency determines the frequency of the output electrical power. Three phase power, with three different outputs may be generated by using three different hall-switch segments, and by switching fields slaved to a microprocessor-controller.

One of the simplest methods of output voltage control for the novel thermoelectric generator is to control the flow of fuel that supplies the burner, producing heat in the thermoelectric system, effecting the amount of stored magnetic energy. By roughly controlling the amount of fuel flow to the burner in the generator, this controls the temperature differential of the junctions of the generator, the heat flowing fairly uniformly through the thermoelectric junctions to cold fins to either a water reservoir that boils away to expel heat, or to ambient air in an air cooled variant by forced air fan. In the simplest variant, by turning up the heat, voltage is increased to the desired 120 volts or 208 volts of output for operation of household and commercial loads. More elaborate, solid state

voltage controls have been used successfully but this is the simplest of concepts for use in third world countries.

An advantage of the present invention is that the thermoelectric generator of the present invention produces useful electrical current by burning any desired type of fuel in a system with no moving parts.

An additional advantage of the present invention is that improved elements, which are made by plating select high-Seebeck materials over oxygen-free partially flattened copper cores with threaded cross sections, decrease resistance from 10^{-6} to 10^{-7} Ω and double the Seebeck voltage for each junction element set. to reduce heat flow, increase temperature differentials, and increase overall thermal-to-electric efficiency of the generator.

One more advantage of the present invention is adding thermal resistors between hot and cold fins, the amount of heat required to drive current is decreased by 80% and has raised thermal-to-electrical efficiency from 4% to 12%.

Yet another advantage of the present invention having a torus made up of thermoelectric elements formed of singular type commercially pure metals coated with complementary high Seebeck voltage materials increases electrical current ten fold because of a ten fold lower resistance in the pure metals in comparison with junctions made from combinations of alloys of pure metals.

Still another advantage of the present invention is that forming metallic planar thermoelectric junctions similar to silicon planar junctions in semiconductor technology, improves the lifetime of the thermoelectric junctions, seals them from the environment, and maintains the high Seebeck voltage characteristics of the thermoelectric junctions over the lifetime of the device.

These and other features, objects and advantages will be understood or apparent to those of ordinary skill in the art from the following detailed description of the preferred embodiment as illustrated in the various drawing figures.

<u>Brief Description of Drawings</u>

FIG. 1 is a perspective view of a thermoelectric generator of the present invention showing the external features and a gas fuel tank;

FIG. 2 is a perspective view showing a torus, thermoelectric elements, and vibrating output switch of the thermoelectric generator;

FIG. 3 is a top plan view showing the torus, thermoelectric elements, and vibrating output switch of the thermoelectric generator;

FIG. 4 is a perspective view of an insulating prestress tie strap used for restraining the thermoelectric generator;

FIG. 5 is a partial top plan view showing the torus, thermoelectric elements, ring, and springs between the thermoelectric elements and the tie strap;

FIG. 6 is a diagrammatic view of an ohmic connection of thermoelectric elements using copper rods between hot and cold copper fins;

FIG. 7 is a diagrammatic view of a complementary connection of the thermoelectric elements using iron rods between the hot and cold copper fins;

FIG. 8 is a diagrammatic view from above showing threaded rod low-thermal-conductivity elements between hot and cold fins together with a corresponding graph below of the temperature gradient between the pair of hot and cold fins versus position between the fins indicating that thermal-to-electric conversion efficiency increases by a factor of ten over that of solid dissimilar materials mated to form thermoelectric couples as illustrated in FIG. 9;

FIG. 9 is a diagrammatic view from above showing solid dissimilar materials between hot and cold fins, together with a corresponding graph below of the temperature gradient between the pair of hot and cold fins versus position between the fins indicating that thermal-to-electric conversion efficiency decreases by one-tenth below that of the threaded rod low-thermal-conductivity elements between hot and cold fins as illustrated in FIG. 8;

FIG. 10 is a schematic partial cross-sectional view showing threaded rod low-thermal-conductivity elements fit into grooves in hot and cold fins;

FIG. 11 is a diagrammatic view showing current path length for a thermoelectric junction with grooved hot and cold fins above, and an electrical model for the thermoelectric junction below;

FIG. 12 is a diagrammatic view showing current path length for a series of thermoelectric junctions with grooved hot and cold fins above, and an electrical model for the series of thermoelectric junctions below;

FIG. 13A is a schematic elevational and cross-sectional views of a threaded rod used as a low-thermal-conductivity element;

FIG. 13B is a schematic elevational and cross-sectional views of a partially flattened threaded rod used as a low-thermal-conductivity element showing a shortened electrical path length across the partially flattened rod;

FIG. 14 is a schematic partial cross-sectional view of a flattened low-thermal-conductivity element aligned for placement in the grooved hot and cold fins;

FIG. 15 is a schematic partial cross-sectional view of a thermocouple showing plated thermoelectric junctions and catalytic coatings on the hot and cold fins;

FIG. 16 is a schematic partial cross-sectional view of a planar thermoelectric junction created by brazing or plating;

FIG. 17 is a schematic cross-sectional view taken through the centerline of the thermoelectric generator showing the black box re-heater returning infrared heat from the exhaust back to the hot fins;

FIG. 18 is a schematic partial cross-sectional view taken through the centerline of the thermoelectric generator showing air cooling;

FIG. 19 is a schematic partial cross-sectional view taken through the centerline of the thermoelectric generator showing water cooling;

FIG. 20 is a schematic top plan view of a water cooled manifold for the thermoelectric generator;

FIG. 21 is a diagrammatic view of an electromechanical self-starting system for the thermoelectric generator using a vibrating switch illustrated in FIG. 25 which utilizes a piezoelectrical generator normally used to ignite a burner in a gas powered thermoelectric generator;

FIG. 22 is a diagrammatic view of a mechanical means of starting the thermoelectric generator using the current interrupting vibrating switch illustrated in FIG. 25;

FIG. 23 is a diagrammatic view of the vibrating current interrupting switch used in extracting electrical power from the thermoelectric generator with the switch in the open circuit position;

FIG. 24 is a diagrammatic view of the vibrating current interrupting switch with the switch in the closed circuit position;

FIG. 25 is a schematic cross-sectional view of the vibrating current interrupting switch in a closed position in A with the dissimilar metal armature pulled up by a solenoid so that the armature threads contact the threads of the hot and cold fins, in the open power mode position in B with the armature in the middle not contacting the hot and cold fins, and in a closed position in C with the armature forced down by a spring so that the armature threads contact the threads of the hot and cold fins;

FIG. 26 is a diagrammatic view showing the vibrating current interrupting switch used with a capacitor tank circuit to improve the sinewave quality of the electrical output waveform;

FIG. 27 is a schematic top plan view showing electrical output connections for the thermoelectric generator using the vibrating current interrupting switch;

FIG. 28 is a diagrammatic view of the thermocouple torus of the thermoelectric generator showing a Hall effect device used to draw power from the torus without interrupting the current flow, demonstrated in A with a superimposed magnetic field facing into the page, and in B with a superimposed magnetic field facing out of the page, illustrating the electron shift as the current crowds to one side in the conductor creating a voltage across the

conductor perpendicular to the magnetic field and to the current flow;

FIG. 29 is a diagrammatic view of the thermocouple torus of the thermoelectric generator showing the Hall effect device which generates the voltage which is interrupted by a mosfet switch to generate an AC output current;

FIG. 30 is a diagrammatic view of the thermocouple torus of the thermoelectric generator showing the current flow in the torus and the related magnetic field;

FIG. 31 is a diagrammatic view of a low-thermal-conductivity element that is also a Hall effect device contacting the hot and cold fins that also illustrates current flow, heat flow, superimposed magnetic field of the Hall effect device and the voltage across the low-thermal-conductivity element;

FIG. 32 is a diagrammatic view of the low-thermal-conductivity elements - Hall effect devices showing the elements sandwiched between the hot and cold fins and electrically connected in series together with an electrical power output circuit;

FIG. 33 is a schematic partially broken view showing a pair of the low-thermal-conductivity elements - Hall effect devices sandwiched between a hot and cold fins;

FIG. 34A is a schematic elevational side view of the six pole electromagnet straddling two low-thermal-conductivity elements - Hall effect devices;

FIG. 34B is a schematic elevational end view of the six pole electromagnet straddling a cold fin;

FIG. 35 is a diagrammatic view of the thermoelectric generator, heating and cooling sources and current flow in the torus operating in the power generation mode with heat supplied to the system;

FIG. 36 is a diagrammatic view of the thermoelectric generator used in the cooling mode for thermoelectric cooling drawing heat into one part of the system and transferring it to another part of the system.

FIG. 37 is a plan view of an alternative embodiment low-thermal-conductivity element formed by abutting two halves to

form an electrically-conductive, low-thermal-conductivity longitudinal surface;

FIG. 38A - 38C are plan views illustrating alternative embodiment thermoelectric junctions formed using the alternative embodiment low-thermal-conductivity element depicted in FIG. 37;

FIG. 39 is a diagrammatic view depicting an alternative technique for generating electrical power from the torus depicted in FIGs 2, 3, 4, and 5; and

FIG. 40 is a diagrammatic view depicting operation of the torus depicted in FIGs 2, 3, 4, and 5 for thermoelectric refrigeration.

Best Mode for Carrying Out the Invention

In FIGs. 1-3 a thermoelectric unit adapted for use as a thermoelectric generator 40 utilizes a high circulating current in a torus 60 of tightly packed thermocouples to produce a usable electrical output. A series of thermocouples is formed into a torus 60 with each thermocouple 55 (as depicted in FIGs. 10 and 15) comprising a hot fin 66 and a cold fin 65 and a low-thermal-conductivity element 64 sandwiched between them. As illustrated in FIGs. 10, 15 and 16 a layer of electrically conductive material layers 67T, 94Au and 94Ag may be interposed between the low-thermal-conductivity element 64 and the fins 65 and 66. The thermoelectric generator 40 further comprise a circumferential means (tie strap 61) for retaining the thermocouples in the torus 60, a means for heating the hot fins 66 (burner 77 in FIG. 17) at a heating end 51 of the hot fins 66 (in FIGs. 6, 7, and 10), a means for cooling (water 82 or air 100 in FIGs. 17-20) the cold fins 65 at a cooling end 53 of the cold fins 65, and a means for drawing an electrical output current from the torus 60 (vibrating switch 70 in FIGs. 3 and 23-27, Hall effect generator 140 in FIG. 29, or Colpits oscillator 159 in FIG. 39). As illustrated in FIG. 35, heat flowing from a heat source 150 across thermoelectric junctions included in the torus 60 to a heat sink 151 induce an electric current to circulate through the torus 60 as indicated by the letter I and arrow in FIG. 35.

In FIGs. 6 and 7 each hot fin 66 is formed into an elongated element having a contact end 52 and a heating end 51 and each

cold fin 65 formed into an elongated element having a contact end 54 and a cooling end 53. Each of the fins 65 and 66 is formed of the same material, i.e. a metal having a high electrical conductivity preferably commercially pure copper. The hot and cold fins 66 and 65 are spaced apart by and in contact at the contact end with at least one low-thermal-conductivity element 64 having a surface formed from a different conductive metal having a high complementary Seebeck voltage. If the low-thermal-conductivity element 64 is formed from a single material, then the material is preferably commercially pure nickel. Each low-thermal-conductivity element 64 may be coated with a layer of an electrically conductive material layer 67 or 67A such as commercially pure copper layer 67 or iron layer 67A for contacting the fins 65 and 66.

In FIGs. 8 and 10-16 the low-thermal-conductivity elements 64T and 64FT and electrically conductive material layer 67 are structured to have low surface area contact with the hot and cold fins 66 and 65 to reduce heat transfer. The low-thermal-conductivity elements 64T and electrically conductive material layer 67T are formed with threads on the exterior surface contacting the hot and cold fins 66 and 65. As illustrated in the graph in FIG. 8, the threaded rod low-thermal-conductivity elements 64T and electrically conductive material layer 67T produce a tenfold increase in temperature difference across the hot and cold thermoelectric junctions resulting in increased thermal to electrical conversion efficiency over non-threaded low-thermal-conductivity elements 64 shown in FIG. 9.

In FIGs. 13 and 14 the low-thermal-conductivity elements 64FT and electrically conductive material layer 67FT are partially flattened as well as threaded to reduce the distance between the hot and cold fins 66G and 65G and the length of travel L of electrical current circulating through the torus 60. The low-thermal-conductivity elements 64T and 64FT and electrical conductors are threaded rods that may be made of nickel and copper, respectively, that are partially flattened into an oval shape for reducing electrical resistance while maintaining a maximum temperature differential between hot and cold fins 66 and 65 and by reducing the length of travel of the current.

In FIGs. 10, 11, 12, and 14, to further reduce the length of L, each of the hot and cold fins 66G and 65G includes at least one groove 38 formed on each side of each fin 65G and 66G at the contact end 52 and 54. The grooves 38 receive the low-thermal-conductivity elements 64FT contacting the electrically conductive material layer 67FT thereby reducing the length of travel L of the current as shown in FIGs. 11 and 12.

In FIGs.15 and 16, each of the threaded low-thermal-conductivity elements 64T and electrically conductive material layer 67T and each of the grooves 38 of the hot and cold fins 66G and 65G is plated with a noble metal layers 94Au and/or 94Ag selected from the group consisting of silver, and gold to increase electrical conductivity at the junction between the low-thermal-conductivity element 64 and the grooves 38 in the fins 65 and 66.

The choice of a material system for interconnecting thermoelectric elements making up the torus 60 is made by considering whether a material with very low electrical resistivity, but contributing no Seebeck voltage, will contribute more to increasing the electrical current circulating through the torus 60, or whether a material of opposite thermoelectric type will contribute enough complimentary Seebeck voltage to offset the material's higher electrical resistivity of the material. For example, a threaded copper low-thermal-conductivity element 64, sandwiched between hot and cold copper fins 66 and 65, produces no Seebeck voltage, but the resistivity of copper is $1.72x10^{-6}$ Ohm-cm , which is very low compared to a metal like nickel at $6.80x10^{-6}$ Ohm-cm that would produce a complementary Seebeck voltage. For a torus 60 using threaded iron low-thermal-conductivity elements 64, that produces $18.5x10^{-6}$ micro-volts/^{0}C, with a resistivity of $9.71x10^{-6}$ Ohm-cm, iron would be the logical choice to maximize the circulating current. The difficulty is, however; that the best iron available (99.99% pure) produces only $3.0x10^{-6}$ micro-volts/C not $18.5x10^{-6}$ micro-volts/^{0}C. In view of this material limitation, a better materials choice would be to use copper low-thermal-conductivity elements 64 to maximize electrical current circulating through the torus 60. If it were possible to obtain better iron at a reasonable price that

produces Seebeck voltage as set forth in handbooks, iron threaded low-thermal-conductivity elements 64 could be used for forming thermoelectric junctions in the torus 60.

FIG. 37 depicts a particularly preferred embodiment of the low-thermal-conductivity element 64 to be interposed between immediately adjacent hot and cold fins 66 and 65. The low-thermal-conductivity element 64 is preferably shaped as a cylindrical pin that fits into the grooves 38 formed in the hot and cold fins 66 and 65. These preferred low-thermal-conductivity elements 64 are formed by thermocompression or thermofusion bonding of two semicircular copper halves that abut each other along an electrically-conductive, low-thermal-conductivity longitudinal surface. Before the two semicircular halves are thermocompression or thermofusion bonded to each other, the surfaces to be juxtaposed are knurled to create ridges that intersect each other when the two halves are juxtaposed. Thermocompression or thermofusion bonding fuses peaks of the intersecting ridges together to provide good electrical conductivity between the two halves while the valleys between the ridges remain open as air holes 89. After the two halves have been joined together, the low-thermal-conductivity elements 64 are disposed between adjacent hot and cold fins 66 and 65 with the low-thermal-conductivity longitudinal surface oriented half way between the hot and cold fins 66 and 65.

To establish thermoelectric junctions, each low-thermal-conductivity element 64 may be coated, e.g. by plating, with a layer of material that provides a complementary high Seebeck voltage. The coating materials may be selected from the group consisting of bismuth, constantan, nickel, selenium, tellurium, silicon, germanium, antimony, nichrome, iron, cadmium, tungsten, gold, copper, zinc, and silver with bismuth and antimony being the preferred materials to respectively provide p-type and n-type junctions. The preferred n-type coating would be a bismuth layer 67Bi depicted in FIG. 38A. The preferred p-type coating would be an antimony layer 67Sb in FIG. 38A. As illustrated in FIG. 38A, the layers 67Bi and 67Sb are different on opposite sides of hot fins 66 and opposite sides of cold fins 65. As illustrated in FIG. 12, threaded and flatened-threaded p-type and n-type low-

thermal-conductivity elements 64 are also coated with conductive layers 67 of the materials listed above, preferably either bismuth and antimony, that are then arranged to have low-thermal-conductivity elements 64 having different layers 67 on opposite sides of the hot and cold fins 66 and 65.

As illustrated in FIG. 38B, in addition to or instead of coating the low-thermal-conductivity elements 64 with a complementary high Seebeck voltage material for forming the thermoelectric junctions, the grooves 38 in the fins 65 and 66 may be coated with that material. The groove 38 on the first side of each fin 65 or 66 is coated with a layer of material, e.g. 88Bi, that provides one type of thermoelectric junction while the groove 38 on the opposite side of each fin 65 or 66 is coated with a layer of material , e.g. 88Sb, that provides the other type of thermoelectric junction. The fins 65 and 66 are then arranged so the same material forms the layer coating grooves 38 that receive the same low-thermal-conductivity element 64. If the low-thermal-conductivity element 64 is not coated with a high complementary Seebeck voltage material, it is still necessary to match material types for the grooves 38 of the hot and cold fin 66 and 65 contacting a common low-thermal-conductivity element 64. However, if the low-thermal-conductivity elements 64 are coated with a high complementary Seebeck voltage material, then the coating on both the element 64 and the juxtaposed coating on the fin 65 or 66 should be the same material.

As depicted in FIG. 38C, the layer of high complementary Seebeck voltage material coating either the fins 65 and 66 or the low-thermal-conductivity elements 64 may be further overcoated with a layer of copper material 87Cu. Overcoating the high complementary Seebeck voltage materials of the layers 67Bi, 67Sb, 88Bi and/or 88Sb with the layer 87Cu facilitates forming a good electrical connection between each low-thermal-conductivity element 64 and the fins 65 and 66 that the element 64 contacts.

In FIGs. 3, 4, and 5 a circumferential means retains the fins 65 and 66 and the low-thermal-conductivity elements 64 of the torus 60. Accordingly, tie strap 61 encircles the torus 60 to contain the Lorentz Force resulting from the circulating electric current. The tie strap 61, preferably a metal belt for

strength, is secured around the torus 60 (which is a current storage device) to maintain a prestress on the electrical junction connections. The tie strap 61 includes an insulating gap 63, preferably a dielectric material such as a ceramic, built into the tie strap 61 with a buckle 68 and spring washers 69 (in FIG. 4) to maintain a prestress in the torus 60. The insulating gap 63 de-couples the tie strap 61 to prevent it from becoming a secondary winding of the torus 60. A dielectric and thermal insulation layer 62 is secured to the tie strap 61 between the tie strap 61 and the torus 60 to prevent the tie strap 61 from electrically or thermally shorting the thermocouples. In FIG. 5 the loop further comprises a plurality of coiled springs 72 secured between the torus 60 of thermocouples and the tie strap 61. The compressed coiled springs 72 enable the tie strap 61 to maintain the stress necessary to overcome the Lorentz Force despite contraction and expansion of the torus 60 due to temperature changes.

After the torus 60 has been assembled with the encircling tie strap 61 and regardless of the form of the low-thermal-conductivity elements 64 interposed between pairs of hot and cold fins 66 and 65, the entire assembly is thermocompression bonded in vacuum at 450 C° for 5 minutes. After thermocompression bonding, the entire torus 60 is plated with an electroless nickel material such as ELNIC 100, high phosphorus process, marketed by MacDermid, Incorporated of Waterbury, Connecticut.

In FIGs. 1 and 17 a means for heating the hot fins 66 at the heating end 51 of the hot fins 66 comprises a ventilated fuel burning area 79 below the hot fins 66 with an exhaust opening 90 above the fuel burning area and each heating end 51 of each hot fin 66 positioned in the fuel burning area 79. Any type of fuel may be burned in the fuel burning area, as in a catalytic burner 77. As illustrated in FIG. 15 each of the hot fins 66G may plated with a layer of platinum or palladium 71 on the non-grooved heating end 51 of the hot fin 66 contacted by combustion gases to serve as a catalytic converter for exhausting gasses from the burning area. Coating the hot fin 66 with the layer 71 reduces pollution and prevents oxidation of the hot fin 66. The electrical output current produced by the thermoelectric

generator 40 may be controlled by controlling the amount of fuel supplied to the fuel burning area.

The fuel burning area 79 is provided with a burner 56 which in the illustration of FIG. 19 is a series of gas jets, and the fuel supplied thereto through a tube 57 comprises a stream of compressed gas fed from an outside tank 50 (FIG. 1). Gaseous fuel supplied to the burner 56, preferably methane, propane or butane gas. The burner 56 may also be supplied with a gassified liquid fuel such as kerosene, diesel fuel, fuel oil, Jet-A, JP-4, JP-6, JP-8 and gasoline. Alternatively, the means for heating the hot fins 66 at the heating end 51 may be a nuclear powered heat source.

In FIG. 17, a black box re-heater 75 covers the fuel burning area 79 around the hot fins 66 to reradiate infrared heat produced by the fuel back to the hot fins 66 to increase thermal efficiency. The black box re-heater 75 includes an outside layer of thermal insulation 74 having a black undersurface 76 and a baffle 78 to prevent radiant heat from going straight out an exhaust opening 90. In FIG. 1 the thermoelectric generator 40 further comprising a supporting base 44 that encloses the torus 60, a cover 43, and a grill 42 above the heat exhaust opening to receive pots and pans used in cooking. A handle 41 on the outside of the thermoelectric generator 40 enables easy transportation of the relatively light unit.

In FIGs. 17-19 a means for cooling the cold fins 65 at the cooling end 53 of the cold fins 65 comprises a cooling chamber 81 or 102. The cooling chamber 81 or 102 contains a fluid 82 or 100 for drawing heat away from the cooling end 53 of the cold fins 65 positioned in the fluid.

In FIG. 18, the fluid is air 100 and the means for cooling includes an air inlet opening 104 into the cooling chamber, an air outlet 101 from the cooling chamber, and a fan 103 in communication with the cooling chamber 102 to circulate the air 100 through the cooling chamber drawing heat away from the cold fins 65. The air from the cooling chamber may be circulated through an external heating system 105, the air giving off heat to the heating system, and the air is further circulated by the fan 103 back through the cooling chamber 102.

In FIGs. 17 and 19 the cooling fluid is a liquid, such as water 82, the cooling chamber is an open trough 81, and the cooling ends 53 of the cold fins 65 are immersed in the water 82 which evaporates giving off water vapor 80 to cool the cooling end 53 of the cold fins 65.

In FIG. 20 the cooling fluid is a liquid, such as water 82, the cooling chamber is a closed manifold 83 encircling the cooling ends 53 of the cold fins 65, and further comprising a pump 85 communicating with the manifold 83. The pump 85 circulates the liquid through the manifold 83, the liquid contacting and drawing heat from the cold fins 65. The warmed water 84 exiting the manifold 83 may be circulated through an external radiator 86 to heat another system and cool the water, then the pump 85 recirculates the water through the manifold 83.

In FIGs. 22-27 a means for drawing an electrical output current from the torus 60. The power output means depicted in these FIGs. include a switch 70 having a longitudinally vibrating threaded armature 131. The armature 131 is coupled through a connecting rod to a solenoid 115 capable of moving the armature 131 in one direction. A spring 138 urges the armature 131 to move in direction opposite to that of the solenoid 115. A threaded hole 139, larger than the armature, is formed between a hot fin 66T and a cold fin 65T both made of similar electrically conductive metals such as commercially pure copper. The hot and cold fins 66T and 65T are separated by threaded ceramic spacers 134 (in FIG. 27). The threaded armature 131 moves longitudinally within the threaded hole 139. The armature 131 is preferably made of a metal that is a thermoelectrically different material from the material forming the hot and cold fins 66 or 65. Both the armature 131 and the threaded hole formed into the hot and cold fins 66T and 65T are threaded with the same pitch, and all together they form an on/off switch for interrupting the circulating electric current flowing through the torus 60.

The longitudinal movement of the dissimilar metal armature 131 results in the production of a Seebeck voltage due to contact of the metallic armature 131 with the material of the hot and cold fins 66T and 65T when the switch is in an electrically

closed position. Movement of the armature 131 to an upper electrically closed position illustrated in FIG. 25A is effected by the solenoid 115, and movement to a down electrically closed position illustrated in FIG. 25C is effected by the spring 138. When the armature 131 is between either electrically closed positions, the switch 70 is in the open position illustrated in FIG. 25B with no thread contact, and the flow of current circulating through the torus 60 is interrupted to produce an electrical output voltage that is useful for driving an external electrical load 95.

An electrical output circuit 130, as depicted in FIGs. 23, 24, and 26, connects with electrical outlets 39 on the outside of the thermoelectric generator 40 illustrated in FIG. 1. FIG. 23 shows the vibrating switch 70 open to generate current I in the output circuit 130. In FIG. 24, the vibrating switch 70 is closed so no current flows into the output circuit 130. The alternation between open and closed positions supplies an alternating current to the load 95. A capacitor tank circuit 133 (in FIG. 26) incorporated into the output circuit 130 filters out glitches in the output AC, and improves the quality of the electrical output making it more like a sinewave.

The hot and cold switch fins 66T and 65T as illustrated in FIG. 27 provide output terminals 135 for energizing a household or a commercial electrical load 95. Alternatively opening and closing the electrical loop provided by the torus 60 produces an alternating voltage in the range of 120/208 volts at 50/60 Hertz. The armature 131 vibrates longitudinally at one-half the frequency of the output voltage that is induced by collapse of a magnetic field 143 illustrated in FIG. 30 caused by breaking circulating electric current.

In FIG. 22, to power the solenoid 115 a sinewave generator 116 receives power through electrical contacts 114 from the thermoelectric generator 40 after it is operating. To start the thermoelectric generator 40 by mechanical means, a hand operated one-way spring powered pendulum 120 is mechanically coupled to the solenoid 115. Rotating on pivot 123, the pendulum 120 is normally biased by a spring 122 against a stop 124. Depressing the end of the pendulum loaded with a mass 121 causes a lifter

125 at the opposite end to activate the solenoid 115. The pendulum 120 is capable of exciting the solenoid 115 to vibrate a number of cycles until the electrical output of the thermoelectric generator 40 can self-power the sinewave generator 116 for driving the solenoid 115.

In FIG. 21 an alternate means for starting the thermoelectric generator comprises a finger operated piezoelectric generator 110 that is used for supplying a burner flame igniting spark 118 by pushing activating button 111. The piezoelectric generator 110 may also be used for storing electrical energy 112 in a capacitor 117, connected through a voltage regulator 113 for powering the sinewave generator 116 to activate the solenoid 115 connected to the vibrating switch 70 as in FIG. 22.

In FIGs. 28-34 the means for drawing an electrical output current from the torus 60 includes a Hall effect generator 140. The Hall effect generator 140 includes an electromagnet 147 for applying a magnetic field 137 perpendicular to the current I flowing in the torus 60. Electrical contacts 149 connect in series with a number of thermoelectric Hall effect elements 146 disposed between hot and cold fins 66 and 65 along a segment of the torus 60. As illustrated in FIG. 31, heat flow indicated by small arrows 144 flows from the hot fin 66 through the thermoelectric Hall effect element 146 to the cold fin 65. Concurrently, a large current indicated by large arrows 145 circulates through the torus 60. The external magnetic field 137 applied perpendicularly to the current 145 induces a voltage across the thermoelectric Hall effect element 146. An electrical output circuit 142 depicted in FIG. 32 connects to the series connected thermoelectric Hall effect elements 146 so that electrical energy to operate an electrical load 95 can be withdrawn from the thermoelectric generator 40 without interrupting current flow I in the torus 60. A preferred form for the thermoelectric elements 146 is an oval shaped piece of nickel and copper, for low-thermal-conductivity elements and conductors respectively, having a dissimilar metal plated on the oval shaped piece in a threaded configuration

FIG. 28 illustrates a magnetic field 137, applied perpendicular to current I flowing in the torus 60, generates a voltage

across the torus, perpendicular to the current and perpendicular to an external magnetic field 137. This transverse voltage is referred to as the Hall voltage. The voltage is caused by current 136 crowding to one side in the conductor, as a result of the applied magnetic field 137. If the magnetic field 137 changes polarity (or be sinusoidal in nature), the Hall voltage will also be sinusoidal, producing AC. As illustrated in FIGs. 29, 32, and 34, the magnetic field 137 is generated by series connected coils 148 that connect in parallel across the series connected thermoelectric Hall effect elements 146. A mosfet 141, also connected in series with the coils 148, permits interrupting an electric current flowing through the coils 148 that produces the external applied magnetic field 137. Thus, by opening and closing the mosfet 141, the external applied magnetic field 137 can alternatively be applied and then removed from the thermoelectric Hall Effect elements 146. In this way electrical power drawn from the torus 60 powers both the external load 95 and production of that electrical power by the Hall effect elements 146.

Three phase power may be generated with three different outputs is available by using three independent Hall effect generators 140 each comprising Hall effect elements 146, coils 148 for generating the external applied magnetic field 147, and the mosfet 141. Coordination of the external applied magnetic fields 137 for each of the Hall effect generators 140 required for the production of three phase power is achieved by switching the mosfet 141 on and off in response to signals from a microprocessor-controller. Generation of three phase power in phase with an electrical power grid may be achieved by sensing operation of the power grid and matching the output frequency and phase produced by the generator 40 to those of the grid.

FIG. 39 depicts an alternative technique for producing electrical power from the torus 60. In the illustration of FIG. 39 a capacitor 160 connects diametrically across the torus 60 thereby forming a parallel resonant circuit Colpits oscillator 159 with inductances of the torus 60. An electrically operated shorting switch 161 connects across several thermoelectric junctions located on one half of the torus 60. Alternatively

opening and closing the switch 161 excites the Colpits oscillator 159 to oscillate at its natural resonant frequency determined by one-quarter of the inductance of the torus 60 and the capacitance of the capacitor 160. Consequently, an AC voltage 162 indicated by a double headed arrow in FIG. 39 appears across terminals 163 connected to the capacitor 160 and to the torus 60. The AC voltage 162 can be supplied for driving the external load 95. A rectifying diode 164, connected to one of the terminals 163, rectifies the AC voltage while a capacitor 165 filters the rectified AC to produce a DC voltage across terminals 166 that may also be supplied for driving the external load 95.

Industrial Applicability

Applications for this new generator product range from emergency home power, motor-home and recreational air conditioning and construction, to rural electrification in Third-World countries. The generator 40 is all solid state, with no moving parts to wear, makes no noise in operation, construction is stainless steel. This a 5-kW generator 40 weighs 12 kg (27 lbs), including a one hour fuel supply. Thermal-to electrical efficiency is approximately 12% at this time, far greater than traditional thermoelectric generators, yet half the efficiency of a gasoline/diesel powered generator. At one-tenth the weight of an engine-powered generator, this type thermoelectric generator has far greater utility for portable applications because of size, weight, capacity, and cost.

As illustrated in FIG. 36, if an electric current flows through thermoelectric junctions making up the torus 60, the Peltier effect causes a temperature gradient. Heat is absorbed on a cold side 151A and rejected at the hot side 150A, thus producing a quiet refrigeration capability. Thermoelectric coolers are also very stable and can be used for temperature stabilization of laser diodes or electronic components such as charge-coupled devices, infrared detectors, low-noise amplifiers, and computer chips. In view of the harmful effect of standard chlorofluorocarbon and greenhouse refrigeration gases on the environment and the need for small-scale localized cooling in computers and electronics, the field of thermoelectrics is in

need of higher performance room-temperature materials than those that currently exist. In addition, as the field of cryoelectronics (utilizing high transition temperature superconducting materials), the need for lower temperature (100 to 200 K) and higher performance thermoelectric devices is becoming more prevalent.

Thermoelectric concepts are also being considered in the automobile industry for use in the next generation vehicle, not only for traction, for climate control as well. Other possible automotive uses range from power generation using waste engine heat, to powered seat coolers for comfort or electronic component cooling. The most common application of these materials today is the small, thermoelectric cooler-warmer, which sells for $80 to $100 at many local stores. It provides cooling to about 25°C below and warming to about 55°C above ambient temperature with just a flip of a switch. It can be plugged into a car cigarette lighter or operated by a small DC power source, useful at remote locations far from AC outlets or supplies of ice. A larger version of this cooler could be important, for example, in biological applications for temperature stabilization of specimens, as well as just keeping a favorite beverage cold. The high-performance thermoelectric unit 40 initially developed for a 5000W generator, while it was not intended to be a cooler, will provide thermoelectric refrigeration because the same advanced material systems used in the 5000W generator design can also function well as a solid-state cooler.

FIG. 40 illustrates one approach for operating the thermoelectric unit 40 for refrigeration. In the illustration of FIG 40 a magnetic coil 170 encircles the torus 60. A winding 171 on the magnetic coil 170 connects in series with an electronic switch 172 and with a series connected capacitor 173 and resistor 174. A driving signal supplied to the electronic switch 172 alternatively closes and opens the series circuit to apply a voltage V across the series connected resistor 174, capacitor 173 and winding 171. The voltage applied across this series connected circuit periodically and repetitively injects an electric current 175, indicated by a small arrow in FIG. 40, into the torus 60 to be superimposed upon a much larger circulating

electric current 176 (e.g. 10,000 amperes), indicated by a large arrow in FIG. 40. The electric current injected into the torus 60 in this way causes heat to be transferred from the cold fins 65 to the hot fins 66 thereby operating the torus 60 as a thermoelectric refrigerator.

Other applications for the thermoelectric unit 40 include generator and storage performance in applications such as: the charging and use as an alternate power supply for an electric automobile, a peak-shaver for industry, a utility protection system for the commercial sector, and as a 600 MWh diurnal grid-leveler for the Utility Industry.

Although the present invention has been described in terms of the presently preferred embodiment, it is to be understood that such disclosure is purely illustrative and is not to be interpreted as limiting. For example, while the present invention has been described in terms of a torroidal arrangement of thermoelectric junction groups, it is to be understood that the torroidal form of the invention is preferred for symmetry of forces, and for ease of fabrication and assembly. That is, all or substantially all of the elements arranged sequentially in groups to form the thermoelectric generation and/or refrigeration unit are shaped identically thereby simplifying their fabrication and assembly into an operable unit. However, the thermoelectric groups of the present invention may be arranged in shapes other than that of the torus 60, e.g. an elliptically shaped closed-loop of thermoelectric elements, a rectangularly shaped closed-loop, a hexagonally shaped closed-loop, etc. Accordingly, it is intended that the following claims encompass all geometrical arrangement of groups of thermoelectric elements in which form a closed loop in which an electric current circulates through such closed loop. Consequently , without departing from the spirit and scope of the invention, various alterations, modifications, and/or alternative applications of the invention will, no doubt, be suggested to those skilled in the art after having read the preceding disclosure. Accordingly, it is intended that the following claims be interpreted as encompassing all alterations, modifications, or alternative applications as fall within the true spirit and scope of the invention.

The Claims

What is claimed is:

1. A thermoelectric unit adaptable either for generating electricity or for refrigeration, the thermoelectric unit utilizing a high circulating current in a closed loop of tightly packed thermocouples, the thermoelectric unit comprising:

a series of thermocouples arranged to form a closed loop, each thermocouple comprising a hot fin and a cold fin and an electrically-conductive, low-thermal-conductivity element sandwiched between each immediately adjacent pair of hot and cold fins, each hot fin formed with an elongated shape having a contact end and a heated end, and each cold fin formed with an elongated shape having a contact end and a cooled end; and each hot fin and cold fin being formed of a high electrical conductivity material, being spaced apart by and in contact at the contact end with at least one low-thermal-conductivity element, materials forming junctions between the fins and the low-thermal-conductivity elements providing a complementary high Seebeck voltage for the thermocouple whereby upon heating the heated ends of the hot fins and cooling the cooled end of the cold fins an electric current circulates through the closed loop of thermocouples; and

a circumferential means for maintaining the thermocouples arranged in the closed loop.

2. The thermoelectric unit of claim 1 wherein the low-thermal-conductivity elements are structured to have low surface area contact with the hot and cold fins to reduce heat transfer therebetween.

3. The thermoelectric unit of claim 2 wherein the low-thermal-conductivity elements have a threaded exterior surface that contacts the hot and cold fins.

4. The thermoelectric unit of claim 3 wherein the low-thermal-conductivity elements are partially flattened thereby reducing

a distance between adjacent hot and cold fins for electrical current flowing through the closed loop.

5. The thermoelectric unit of claim 3 wherein each of the hot and cold fins is formed with at least a groove on opposite sides of each fin to receive one of the low-thermal-conductivity elements thereby reducing a distance of travel for electric current flowing through the closed loop.

6. The thermoelectric unit of claim 5 wherein the low-thermal-conductivity elements and the grooves in the hot and cold fins are coated with a dissimilar metal for the junctions between the fins and the low-thermal-conductivity elements that provide a complementary high Seebeck voltage for the thermocouples.

7. The thermoelectric unit of claim 6 wherein the dissimilar metal is selected from a group consisting of bismuth, constantan, nickel, selenium, tellurium, silicon, germanium, antimony, nichrome, iron, cadmium, tungsten, gold, copper, zinc, and silver.

8. The thermoelectric unit of claim 1 wherein:

the hot and cold fins are formed with at least a groove in both a first side and in a second side of each fin, each groove receiving one of the low-thermal-conductivity elements thereby reducing a distance of travel for electric current flowing through the closed loop; and

the low-thermal-conductivity elements being formed with two halves that abut each other along an electrically-conductive, low-thermal-conductivity longitudinal surface, the low-thermal-conductivity elements being oriented so the low-thermal-conductivity surface is disposed between the hot and cold fins that contact the low-thermal-conductivity element thereby reducing thermal conductivity between the hot and cold fins.

9. The thermoelectric unit of claim 8 wherein each low-thermal-conductivity element is coated with a layer of material for the junctions between the fins and the low-thermal-conductivity

elements that provide a complementary high Seebeck voltage for the thermocouples that is selected from a group consisting of bismuth, constantan, nickel, selenium, tellurium, silicon, germanium, antimony, nichrome, iron, cadmium, tungsten, gold, copper, zinc, and silver.

10. The thermoelectric unit of claim 9 wherein the layer coating each low-thermal-conductivity element is over-coated with an electrically-conductive layer.

11. The thermoelectric unit of claim 8:

wherein the groove on the first side of each fin is coated with a layer of material for the junctions between the fins and the low-thermal-conductivity elements that provide a complementary high Seebeck voltage for the thermocouples that is selected from a group consisting of bismuth, constantan, nickel, selenium, tellurium, silicon, germanium, antimony, nichrome, iron, cadmium, tungsten, gold, copper, zinc, and silver; and

wherein the groove on the second side of each fin is coated with a layer of material for the junctions between the fins and the low-thermal-conductivity elements that provide a complementary high Seebeck voltage for the thermocouples that is also selected from a group consisting of bismuth, constantan, nickel, selenium, tellurium, silicon, germanium, antimony, nichrome, iron, cadmium, tungsten, gold, copper, zinc, and silver, and the material forming the layer on the second side of each fin having opposite Seebeck voltage with respect to the material forming the layer on the first side of each fin, the fins being arranged so the same material forms the layer coating grooves that receive the same low-thermal-conductivity element.

12. The thermoelectric unit of claim 11 wherein the layers coating the grooves on each fin is over-coated with an electrically-conductive layer.

13. The thermoelectric unit of claim 1 wherein the circumferential means for maintaining the thermocouples arranged in the closed loop comprises a tie strap that encircles the

closed loop of thermocouples to contain the Lorentz Force that builds up in the closed loop, the tie strap secured around the closed loop applying a prestress to the to the hot and cold fins and low-thermal-conductivity elements of the thermoelectric unit, and the tie strap including an insulating gap that de-couples the strap as a secondary winding coupled to an electric current circulating through the closed loop of thermocouples.

14. The thermoelectric unit of claim 13 further comprising a plurality of coiled springs secured between the closed loop of thermocouples and the tie strap, the coiled springs normally under compression enable the tie strap to maintain the stress necessary to overcome the Lorentz Force despite contraction and expansion of the closed loop due to temperature changes.

15. The thermoelectric unit of claim 1 further comprising:

a fin heating means for supplying heat to the heated end of the hot fins;

a fin cooling means for removing heat from the cooled end of the cold fins; and

a power output means for drawing an electrical output current from the closed loop whereby the thermoelectric unit becomes a thermoelectric generator.

16. The thermoelectric unit of claim 15 wherein the heated end of the hot fins is coated with a material selected from a group consisting of platinum and palladium to provide a catalytic converter for gases exhausted from the fin heating means thereby reducing both pollution and oxidation of the hot fin.

17. The thermoelectric unit of claim 15 wherein the fin heating means comprises a ventilated fuel burning area below the hot fins with an exhaust opening above the fuel burning area, heated end of hot fins being positioned in the fuel burning area.

18. The thermoelectric unit of claim 17 wherein the fuel burning area further comprises a series of gas jets which receive

a fuel comprised of a stream of compressed gas fed into the gas jets.

19. The thermoelectric unit of claim 18 wherein the compressed gas selected from a group consisting of methane, propane and butane.

20. The thermoelectric unit of claim 17 further comprising a grill on top of the thermoelectric unit above the exhaust opening to receive pots and pans for use in cooking.

21. The thermoelectric unit of claim 17 further comprising a black box re-heater in the fuel burning area around the hot fins to reradiate infrared heat produced by the fuel back to the hot fins.

22. The thermoelectric unit of claim 17 wherein the fuel burning area further comprises a burner that receives a gassified liquid fuel selected from a group consisting of kerosene, diesel fuel, fuel oil, Jet-A, JP-4, JP-6, JP-8 and gasoline.

23. The thermoelectric unit of claim 15 wherein the fin heating means comprises a nuclear powered heat source.

24. The thermoelectric unit of claim 15 wherein the fin cooling means comprises a cooling chamber included in the thermoelectric unit, the cooled end of cold fins being positioned in the cooling chamber, the cooling chamber being adapted to retain a fluid for drawing heat away from the cooled end of the cold fins positioned in the cooling chamber.

25. The thermoelectric unit of claim 24 wherein the fluid is air and further comprising an air inlet opening into the cooling chamber and an air outlet opening from the cooling chamber, and a fan in communication with the cooling chamber to circulate the air through the cooling chamber for drawing heat away from the cold fins.

26. The thermoelectric unit of claim 25 wherein the air from the cooling chamber is circulated through an external heating system, the air giving off heat to the heating system and then being circulated by the fan back through the cooling chamber.

27. The thermoelectric unit of claim 24 wherein the fluid is a liquid, the cooling chamber is an open trough, and the cooled ends of the cold fins are immersed in the liquid.

28. The thermoelectric unit of claim 24 wherein the fluid is a liquid, and the cooling chamber is a closed manifold encircling the cooled end of the cold fins, and the thermoelectric unit further comprises a pump communicating with the manifold, the pump pumping the liquid through the manifold, the liquid contacting and drawing heat from the cold fins.

29. The thermoelectric unit of claim 28 wherein the fluid from the closed manifold circulates through an external radiator for cooling the fluid, and then recirculates through the manifold.

30. The thermoelectric unit of claim 15 wherein the power output means for drawing an electrical output current from the closed loop comprises:

a switch that includes an electrically-conductive, longitudinally-vibrating threaded armature, a solenoid for ,urging the armature to move longitudinally in one direction, and a spring for urging the armature to move longitudinally in an opposite direction;

a threaded hole larger than the armature that is formed between a pair of fins that are held apart by threaded ceramic spacers, within which larger threaded hole in the armature may move longitudinally, both the armature and the hole being threaded with the same pitch, and all together forming an on/off switch for opening and closing the current loop responsive to longitudinal movement of the armature, the armature moving from one electrically closed position by the solenoid to an alterna-

tive electrically closed position by the spring, and when the armature is in between either electrically closed positions the flow of current in the closed loop being interrupted to produce an electrical output for driving an external electrical load via an electrical output circuit.

31. The thermoelectric unit of claim 30 wherein the electrical output circuit includes a capacitor tank circuit.

32. The thermoelectric unit of claim 30 further comprising a sinewave generator that is coupled to the solenoid and that receives electrical power from the thermoelectric unit after the thermoelectric unit is operating to drive an external electrical load, and a hand operated exciting means mechanically coupled to the threaded armature and to the solenoid for starting oscillation of the threaded armature and solenoid until the electrical output of the thermoelectric unit can power operation of the sinewave generator.

33. The thermoelectric unit of claim 30 further comprising:
a sinewave generator that is coupled to the solenoid and that receives electrical power from the thermoelectric unit after the thermoelectric unit is operating to power the solenoid; and
a finger operated piezoelectric means for storing electrical energy to power the sinewave generator.

34. The thermoelectric unit of claim 30 wherein materials forming junctions between the threaded armature and of the threaded hole provide a complementary high Seebeck voltage.

35. The thermoelectric unit of claim 15 wherein the power output means for drawing an electrical output current from the closed loop comprises a Hall-Effect switch that includes means for applying a magnetic field perpendicular to the current flowing in the closed loop , electrical contacts connected across a segment of the closed loop, and an electrical output circuit connected to the contacts, so that electrical energy for

operating an external electrical load can be withdrawn without interrupting current flow in the closed loop.

36. The thermoelectric unit of claim 35 comprising connecting three Hall-Effect switches with three different outputs to the closed loop and appropriately applying the perpendicular magnetic field to generate three phase electrical power.

37. The thermoelectric unit of claim 15 wherein the power output means for drawing an electrical output current from the closed loop comprises:

an electronic switch connected across a plurality of thermocouples of the closed loop that may be closed for electrically shorting the plurality of thermocouples;

a capacitor connected across a plurality of thermocouples of the closed loop thereby forming a parallel resonant circuit with inductances of the closed loop; and

electronic switch driving means for causing the electronic switch to alternatively open and close thereby inducing an alternating current ("AC") voltage across the capacitor for driving an external electrical load.

38. The thermoelectric unit of claim 37 further comprising a rectifier for converting the AC voltage across the capacitor into a direct current ("DC") voltage.

39. The thermoelectric unit of claim 1 further comprising:

a fin cooling means for removing heat from the heated end of the hot fins;

a fin heating means for supplying heat to the cooled end of the cold fins; and

a power supply means for supplying an electrical input current to the closed loop whereby the thermoelectric unit becomes a thermoelectric refrigerator.

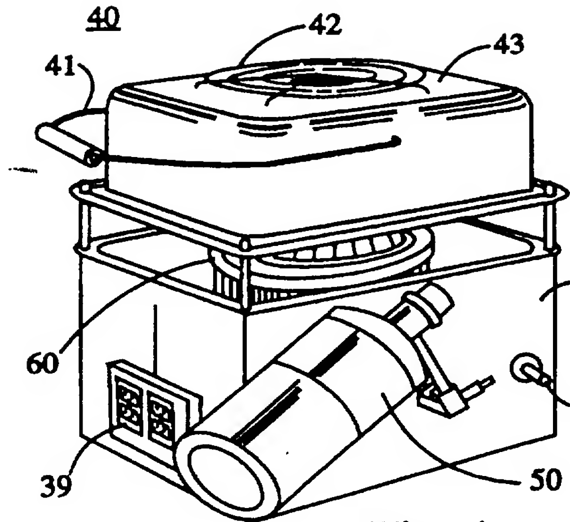

Fig. 1

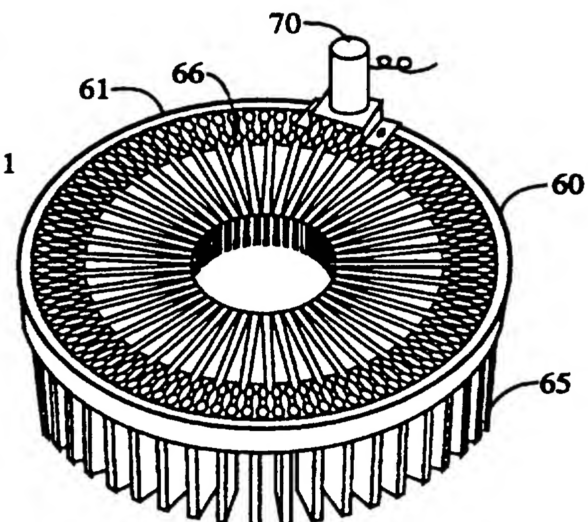

Fig. 2

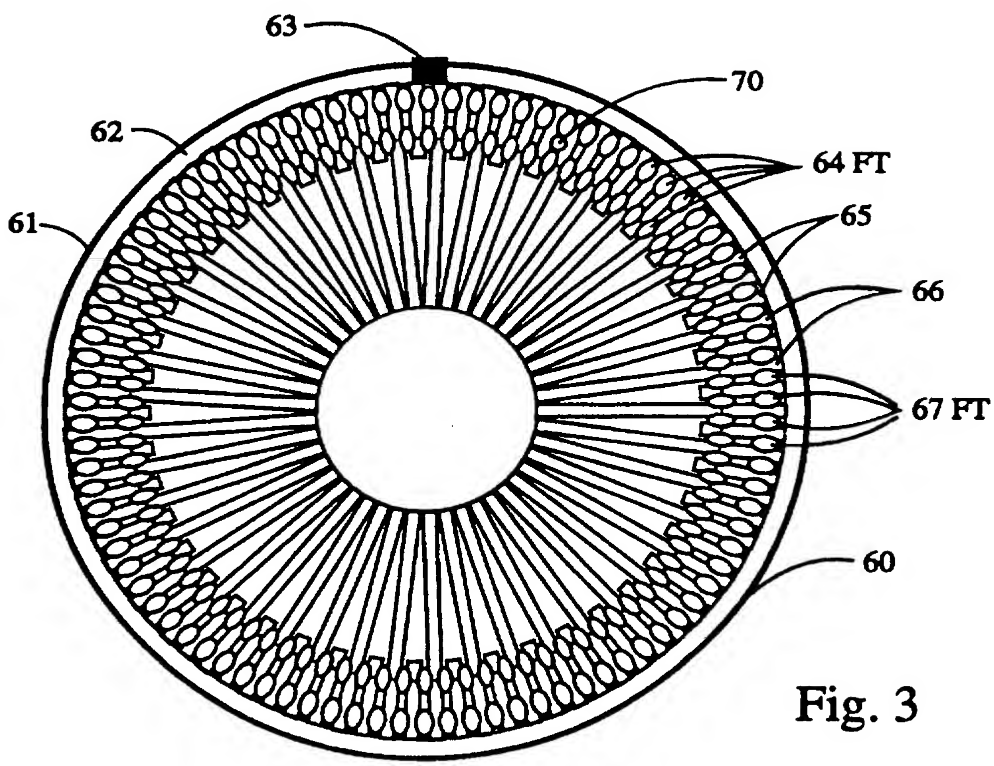

Fig. 3

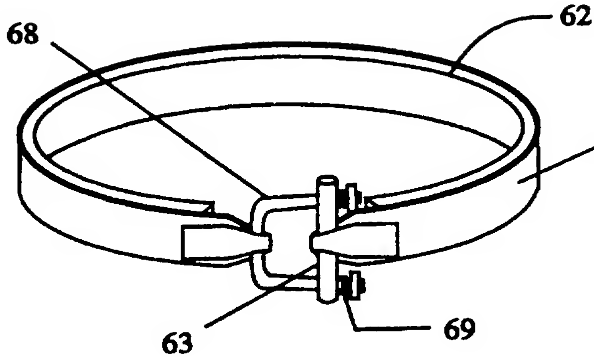

Fig. 4

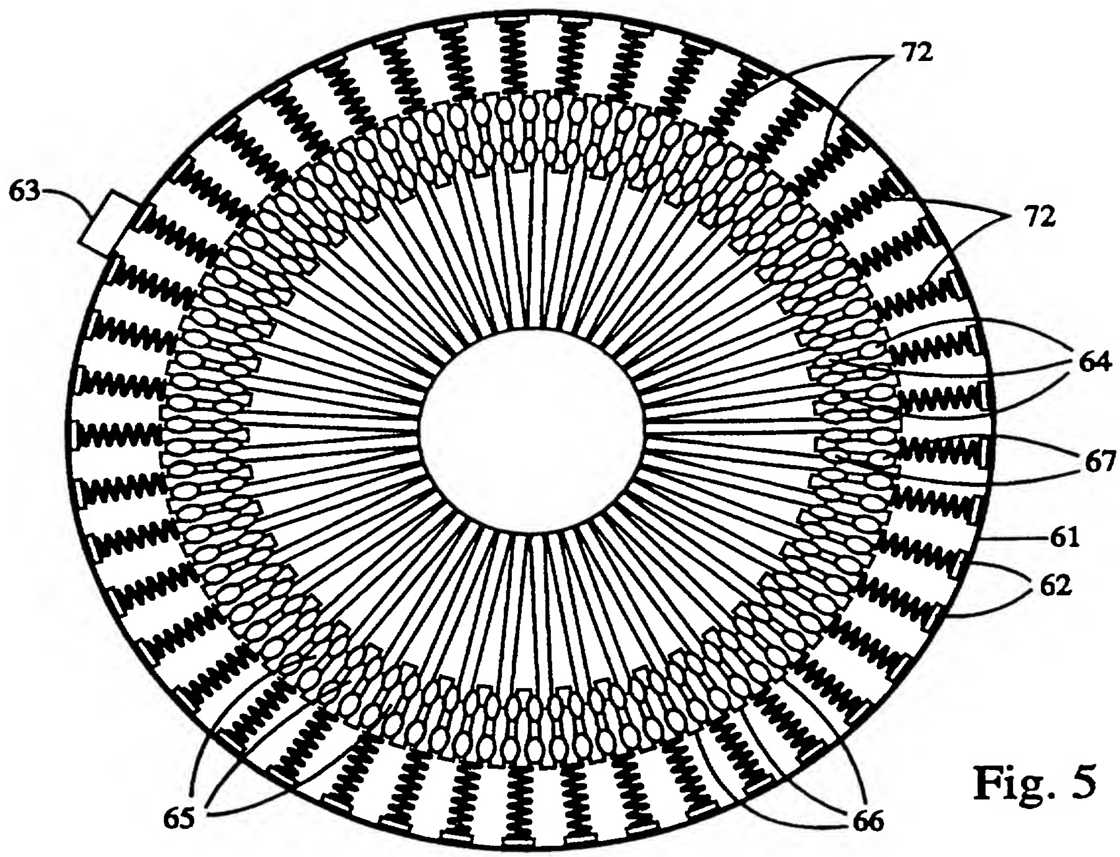

Fig. 5

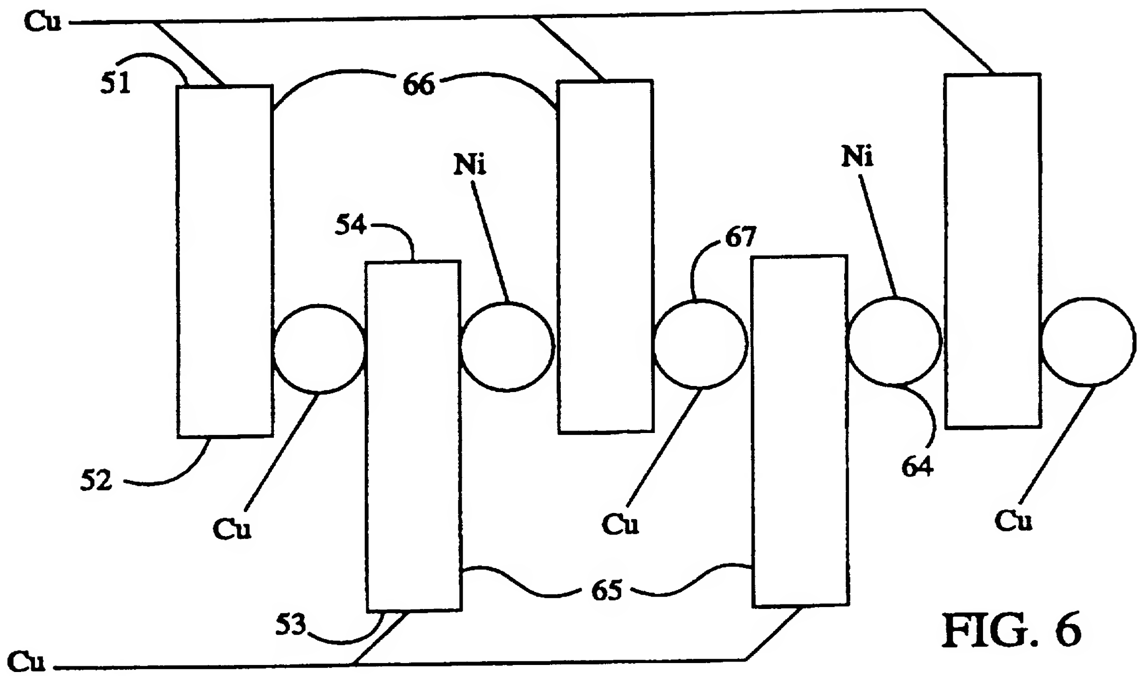
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FIG. 6

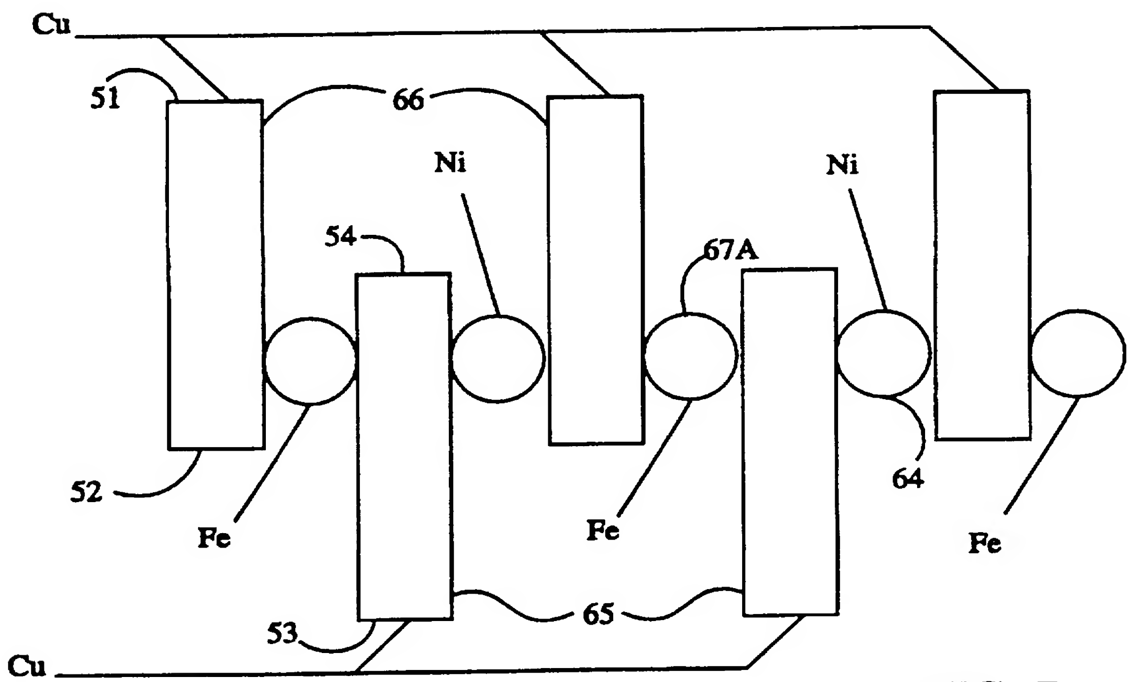
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FIG. 7

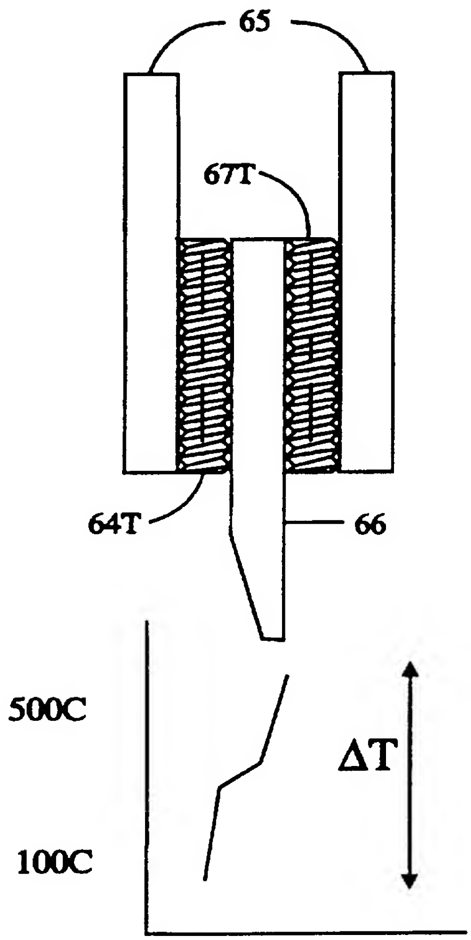


FIG. 8

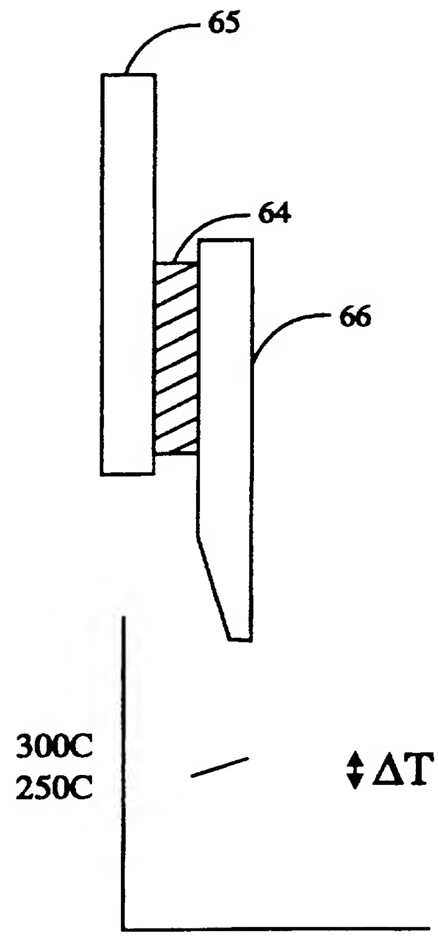
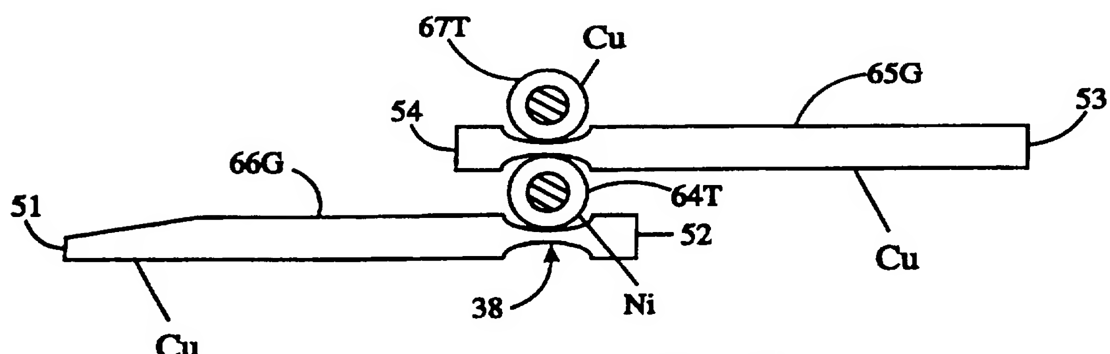


FIG. 9



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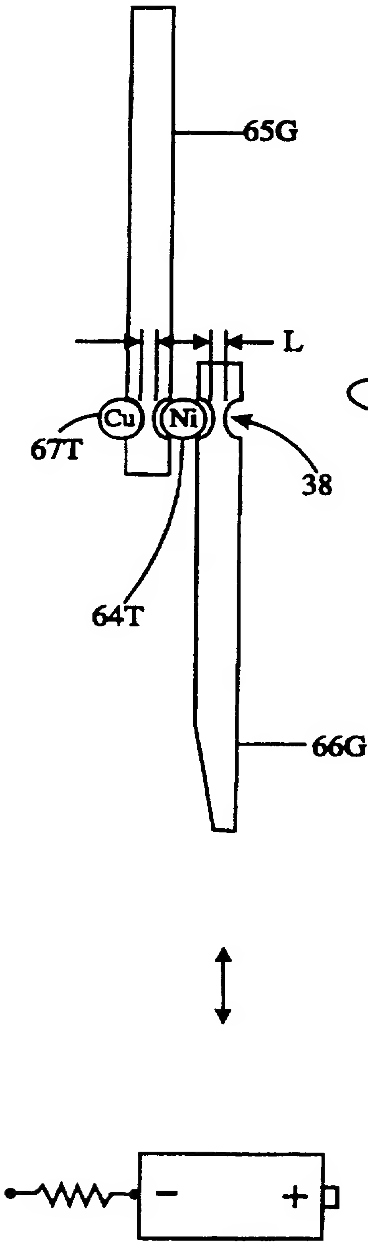

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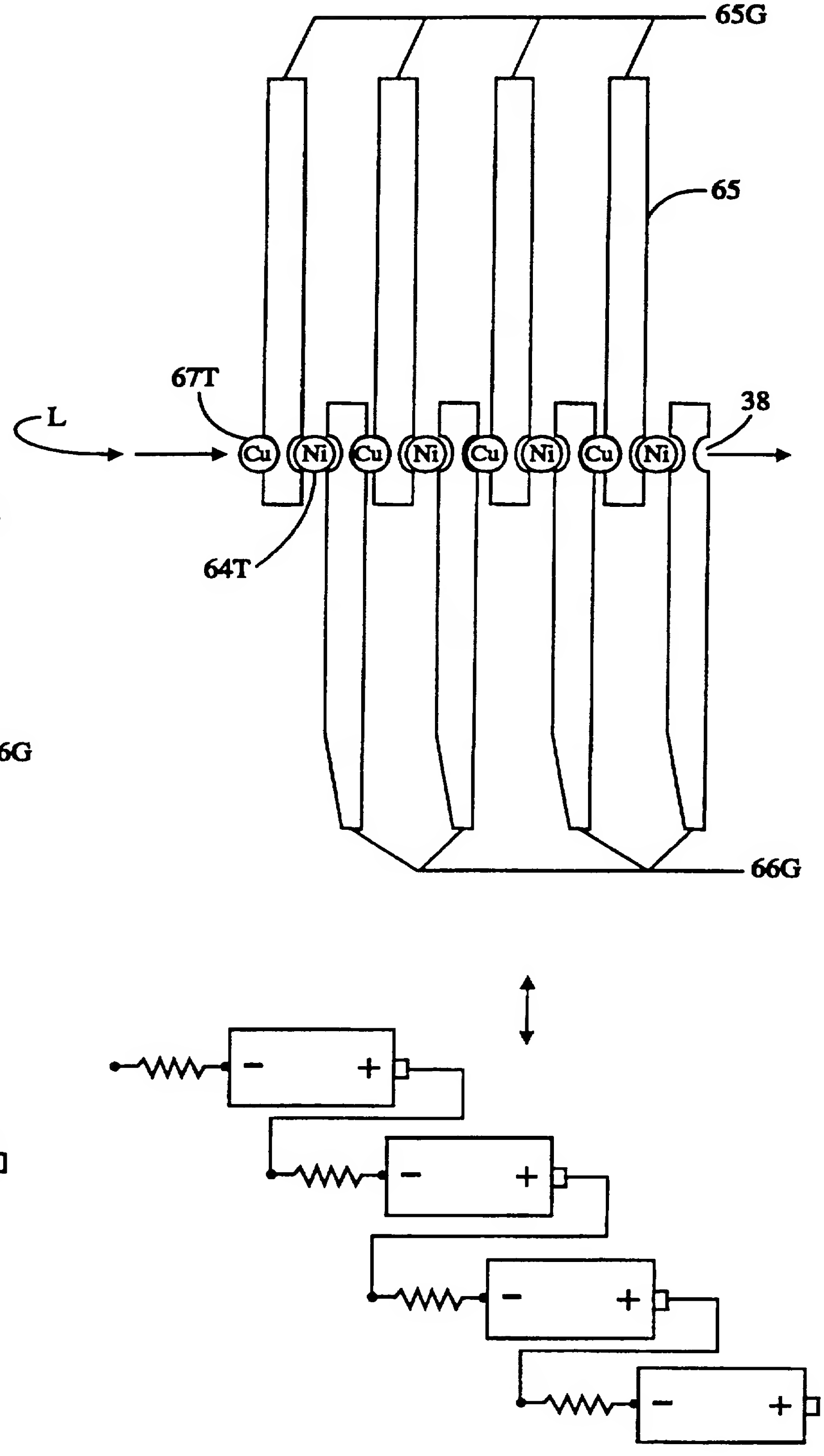

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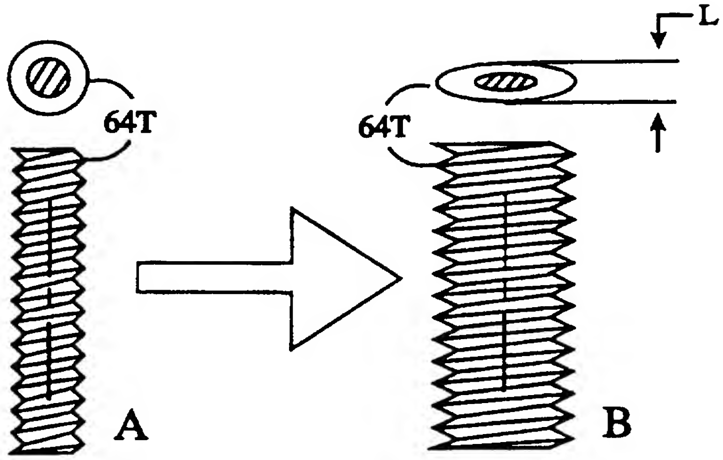

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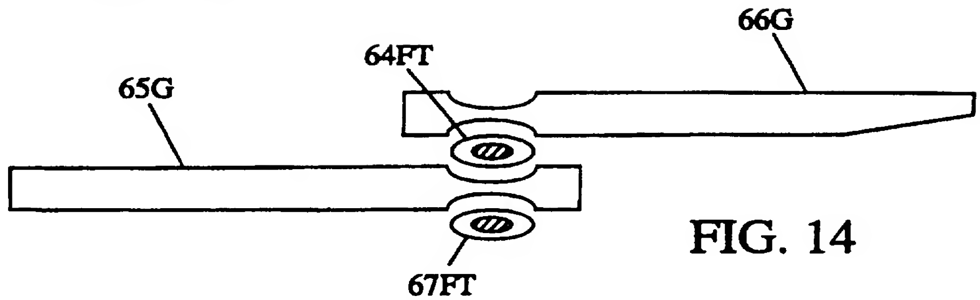

FIG. 14

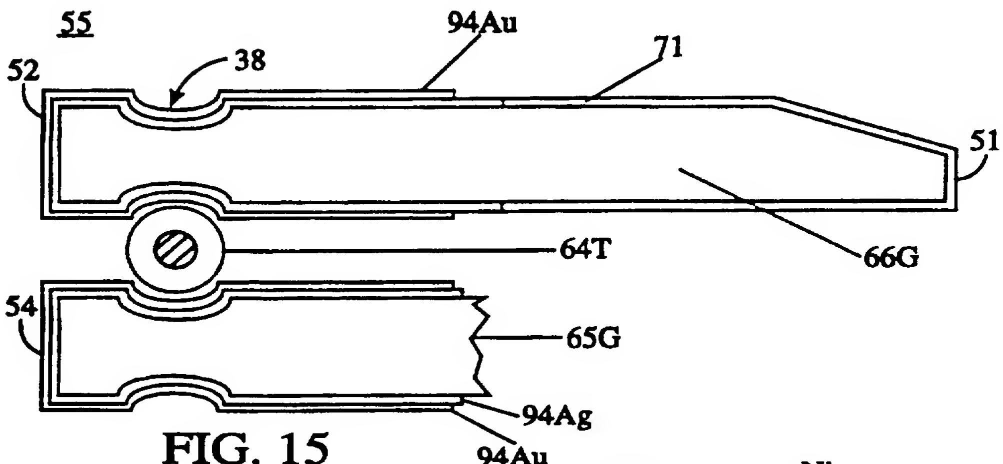

FIG. 15

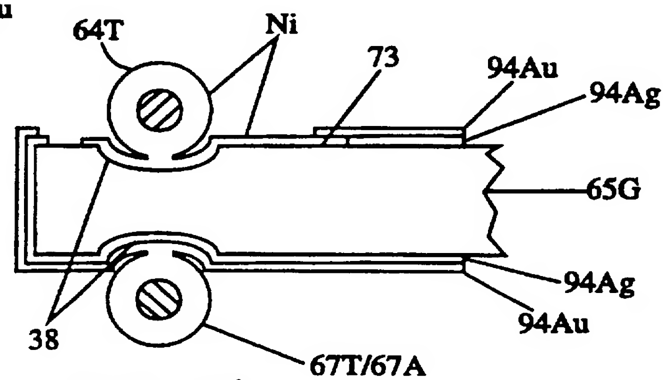

FIG. 16

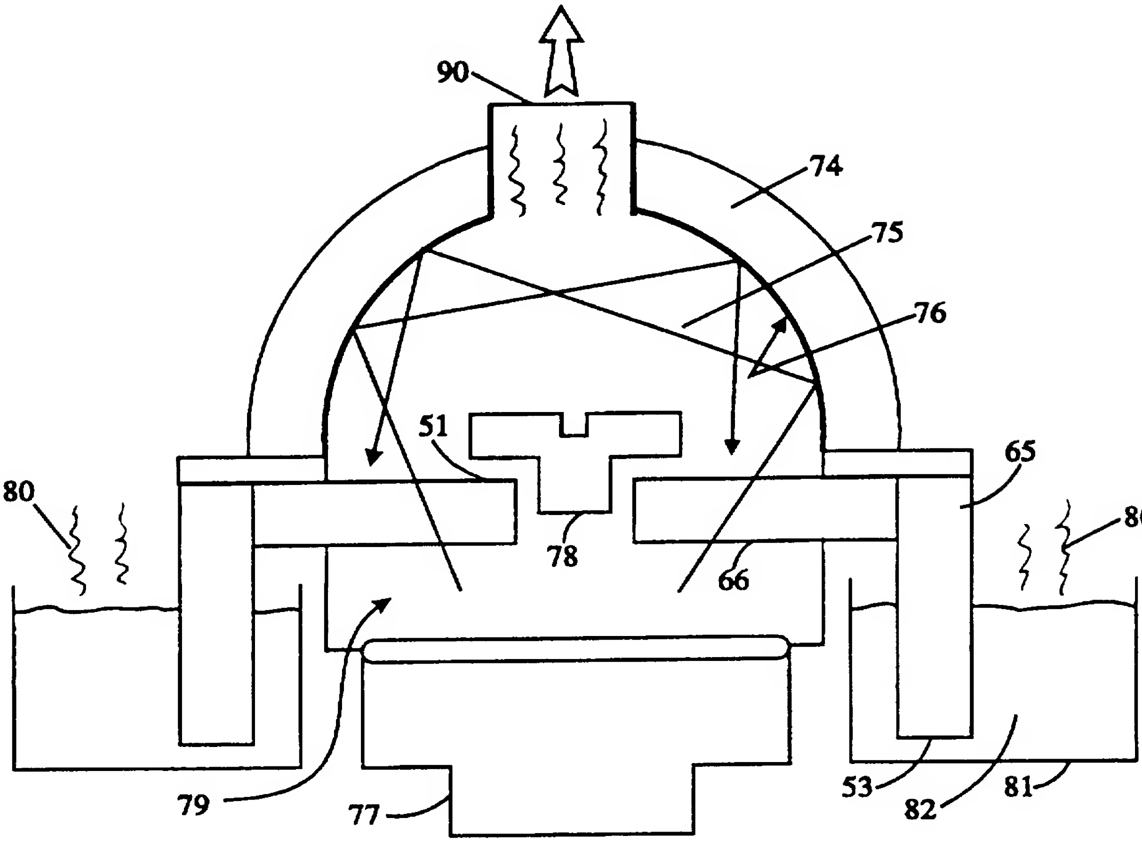
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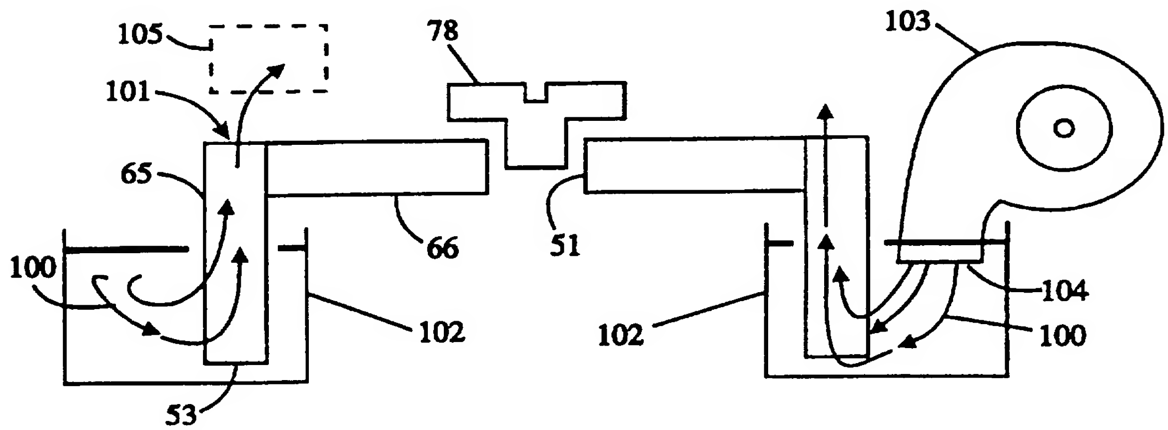
FIG. 17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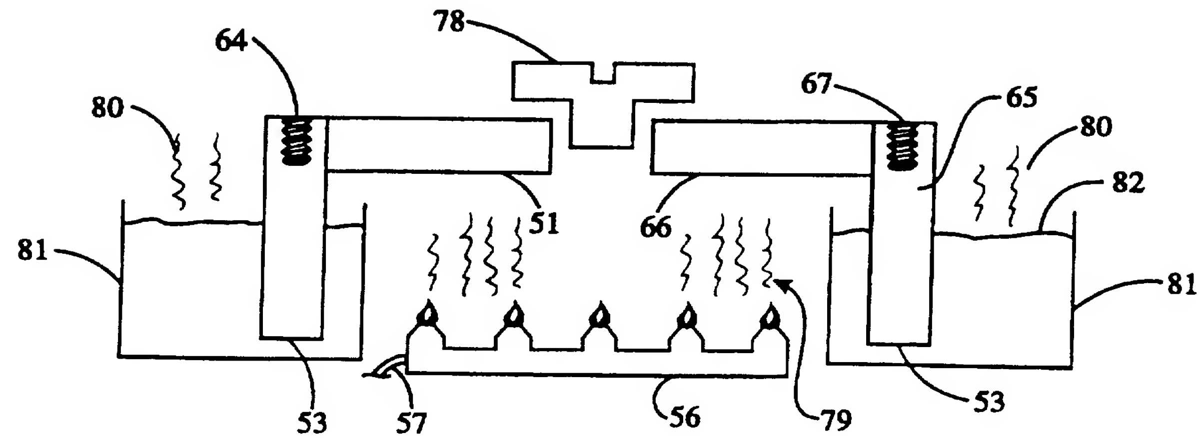
53

FIG. 18



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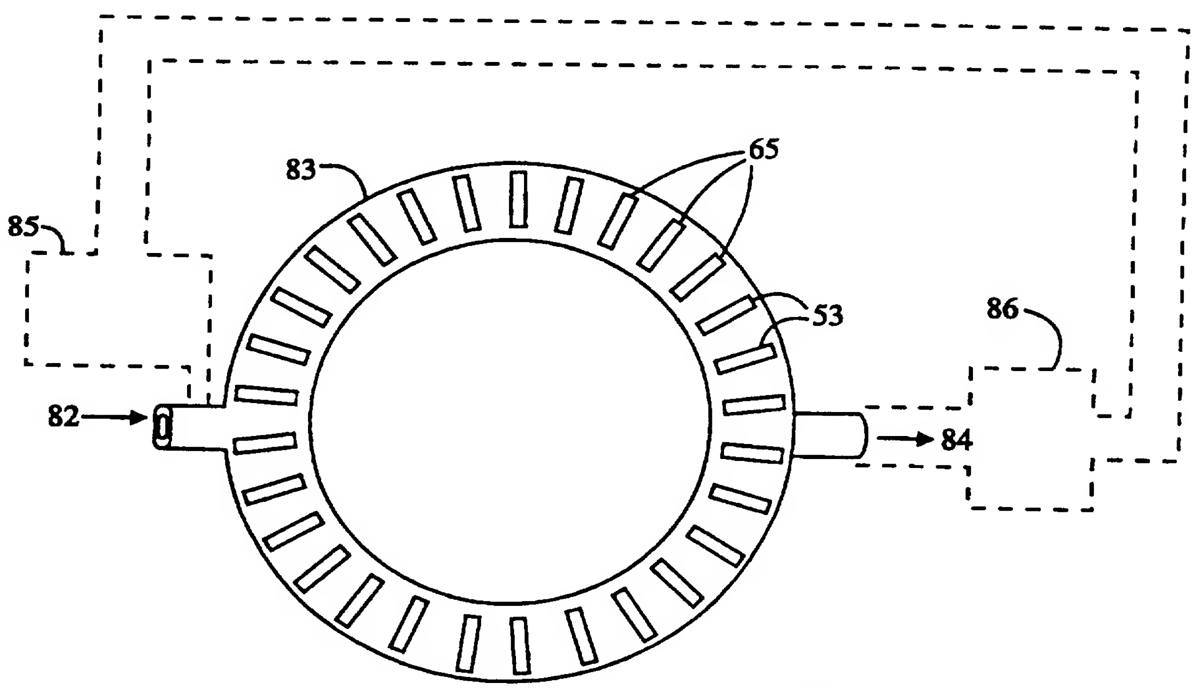


FIG. 20

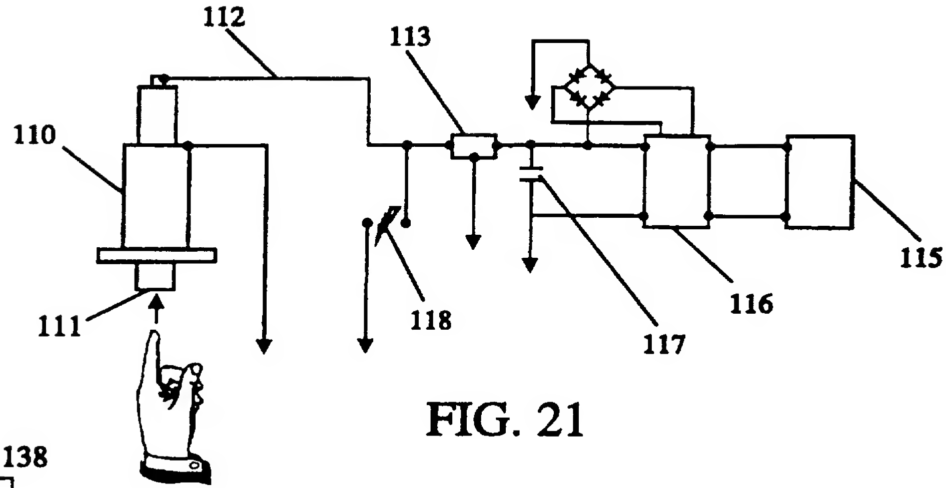
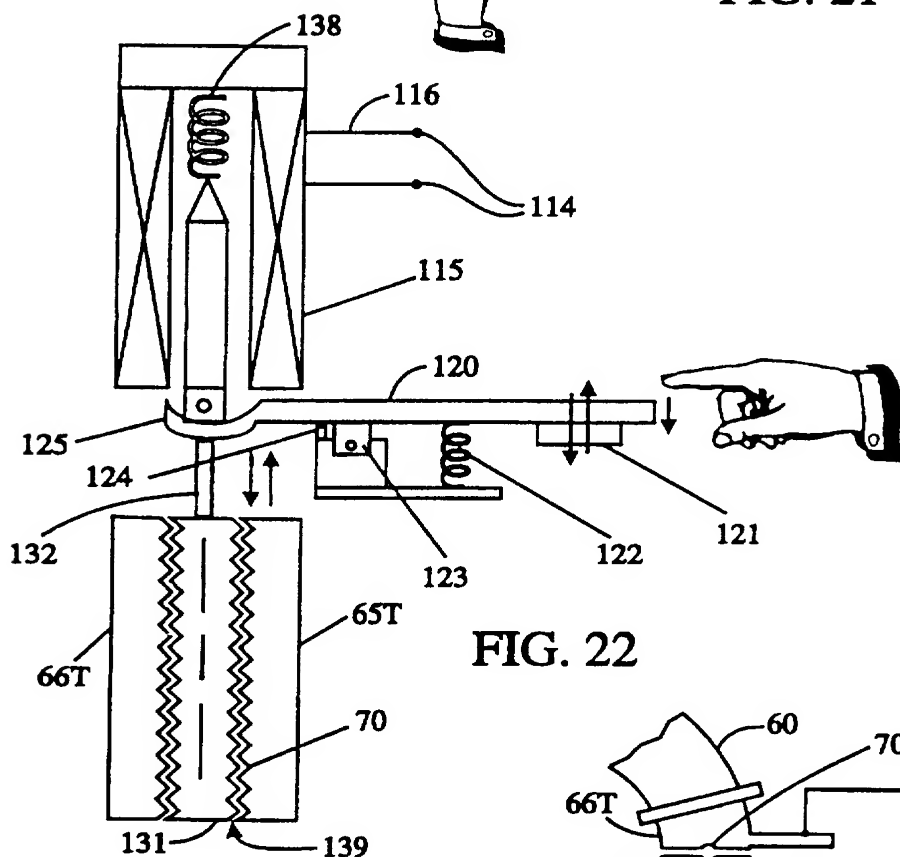


FIG. 21



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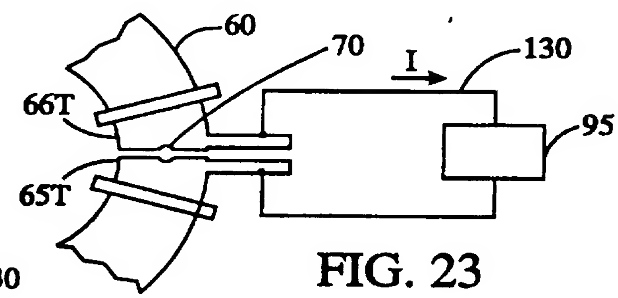

FIG. 23

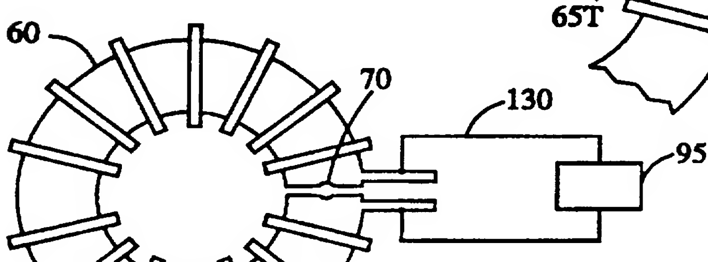

FIG. 24

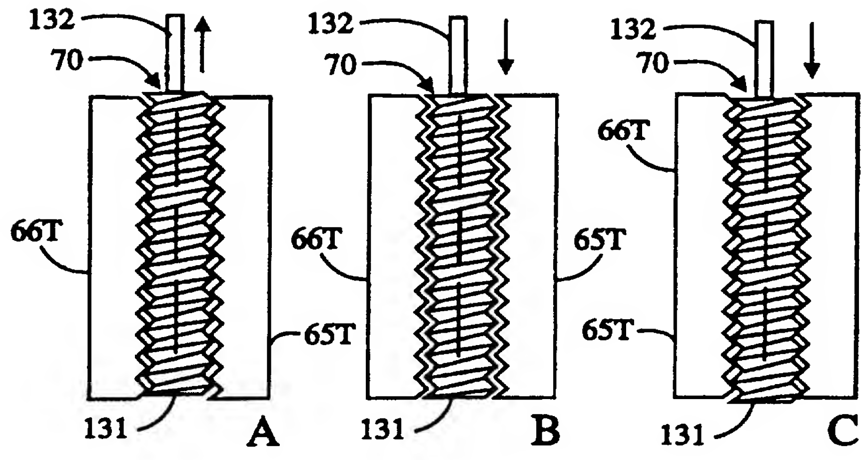

FIG. 25

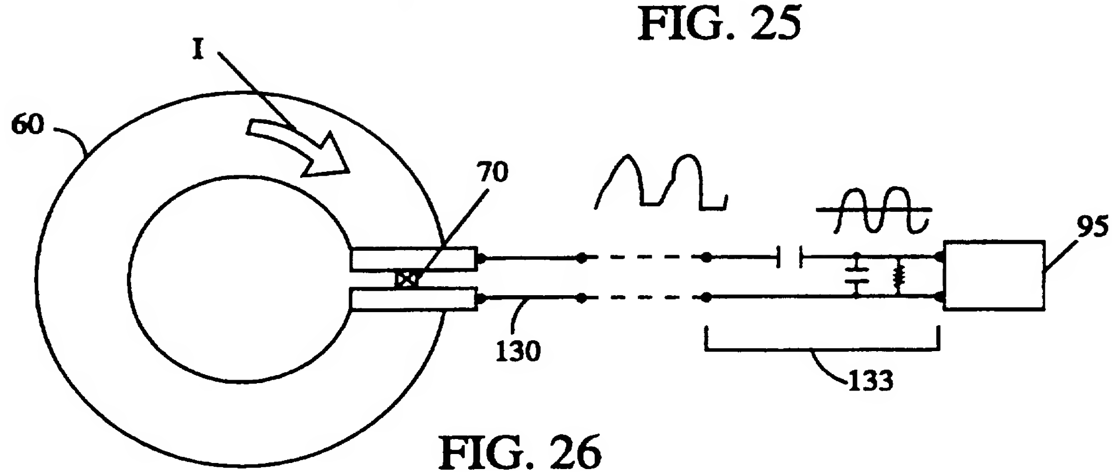

FIG. 26

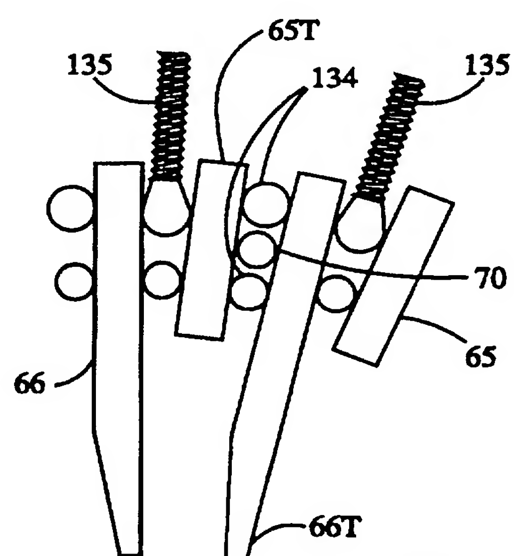

FIG. 27

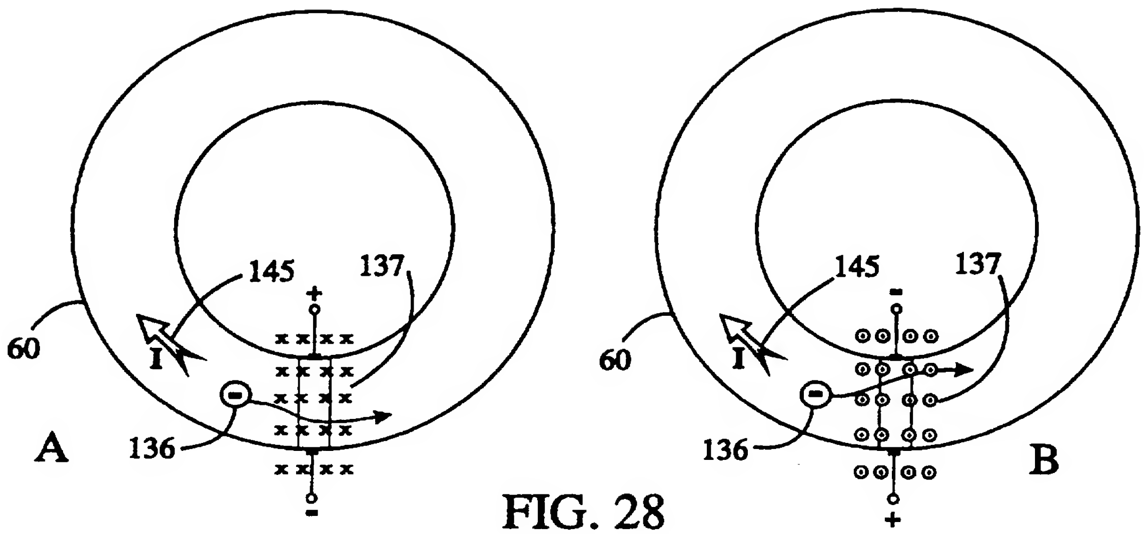

FIG. 28

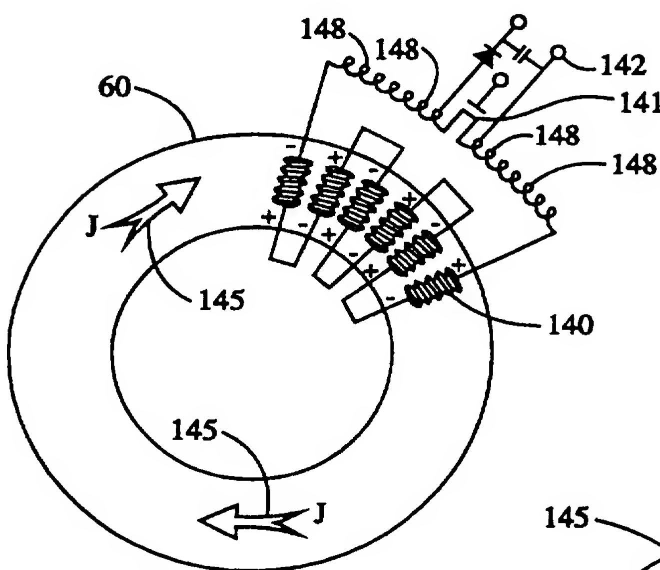

FIG. 29

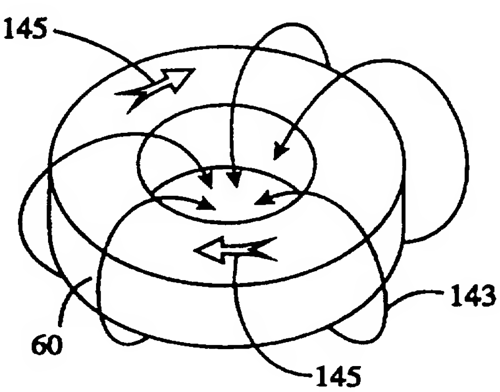

FIG. 30

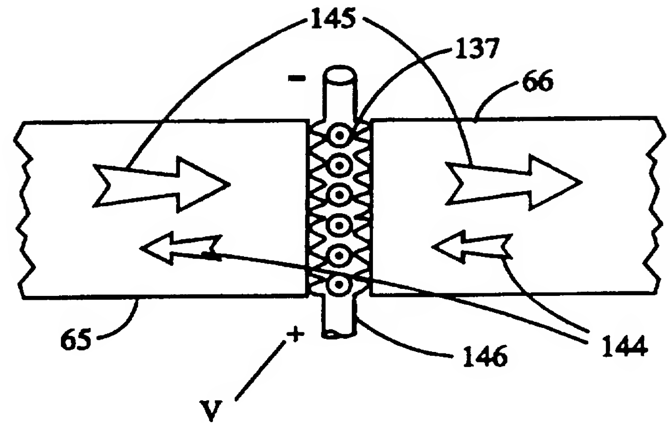
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FIG. 31

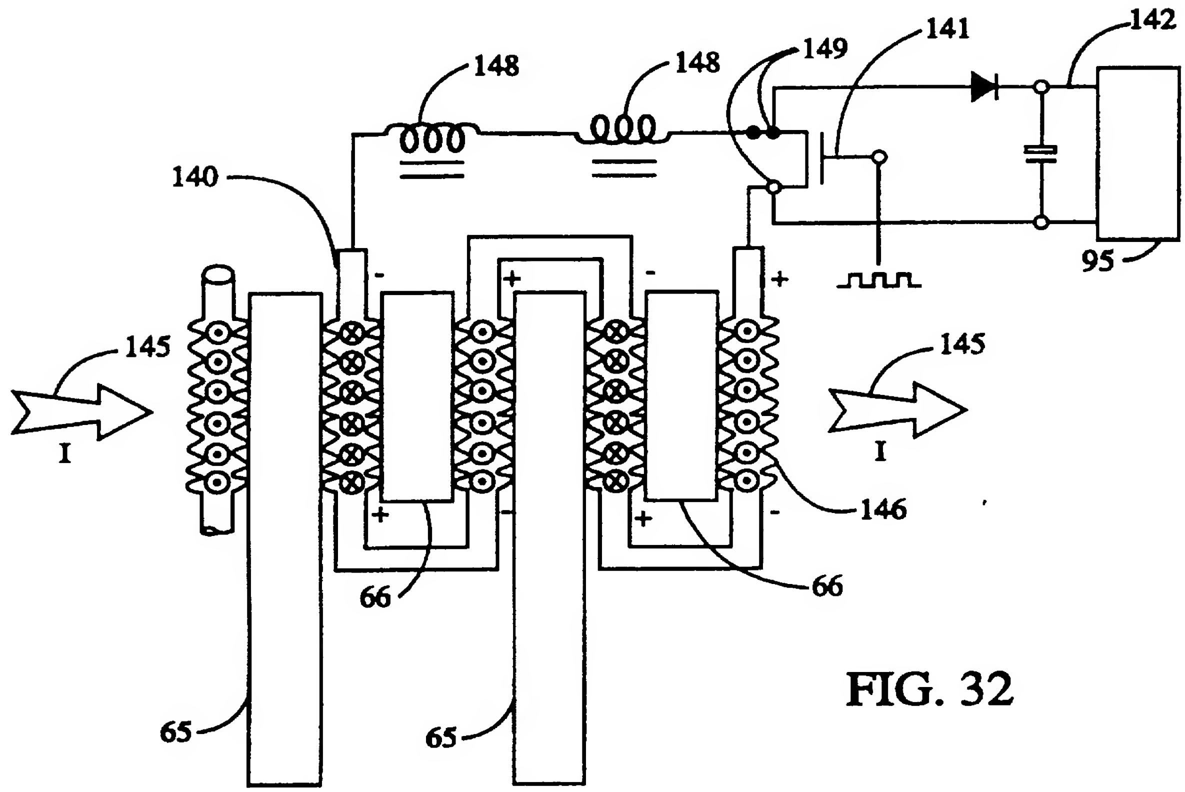
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FIG. 32

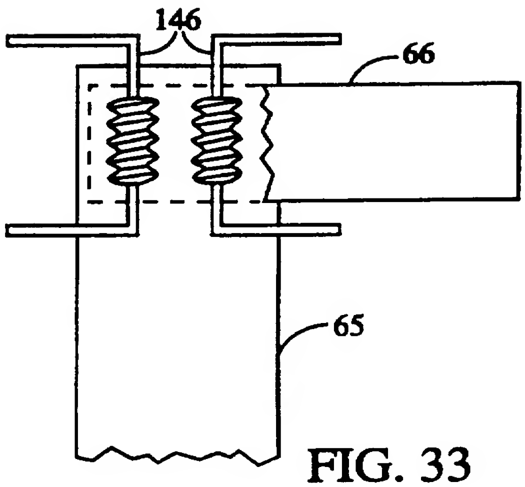


FIG. 33

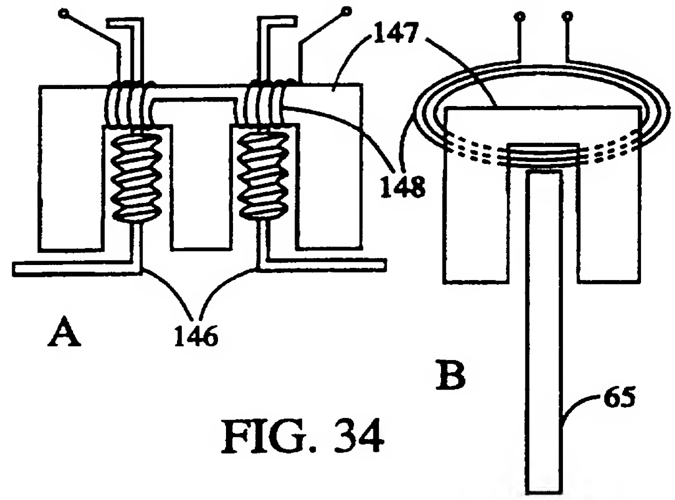


FIG. 34

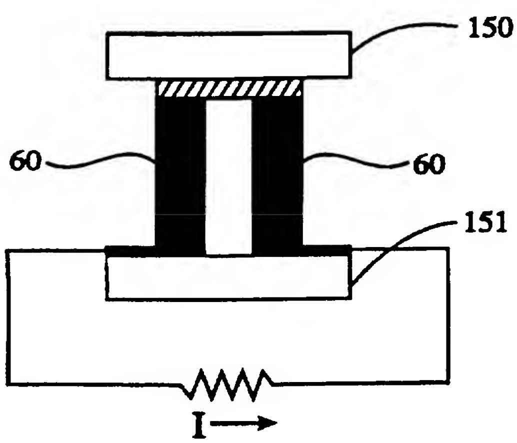
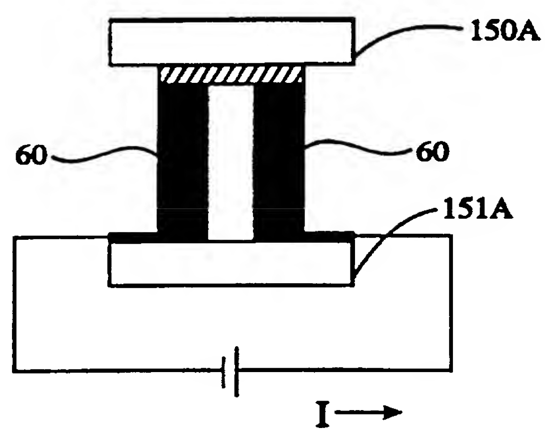


FIG. 35



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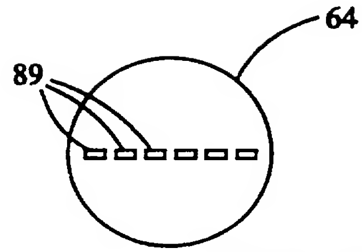

FIG. 37

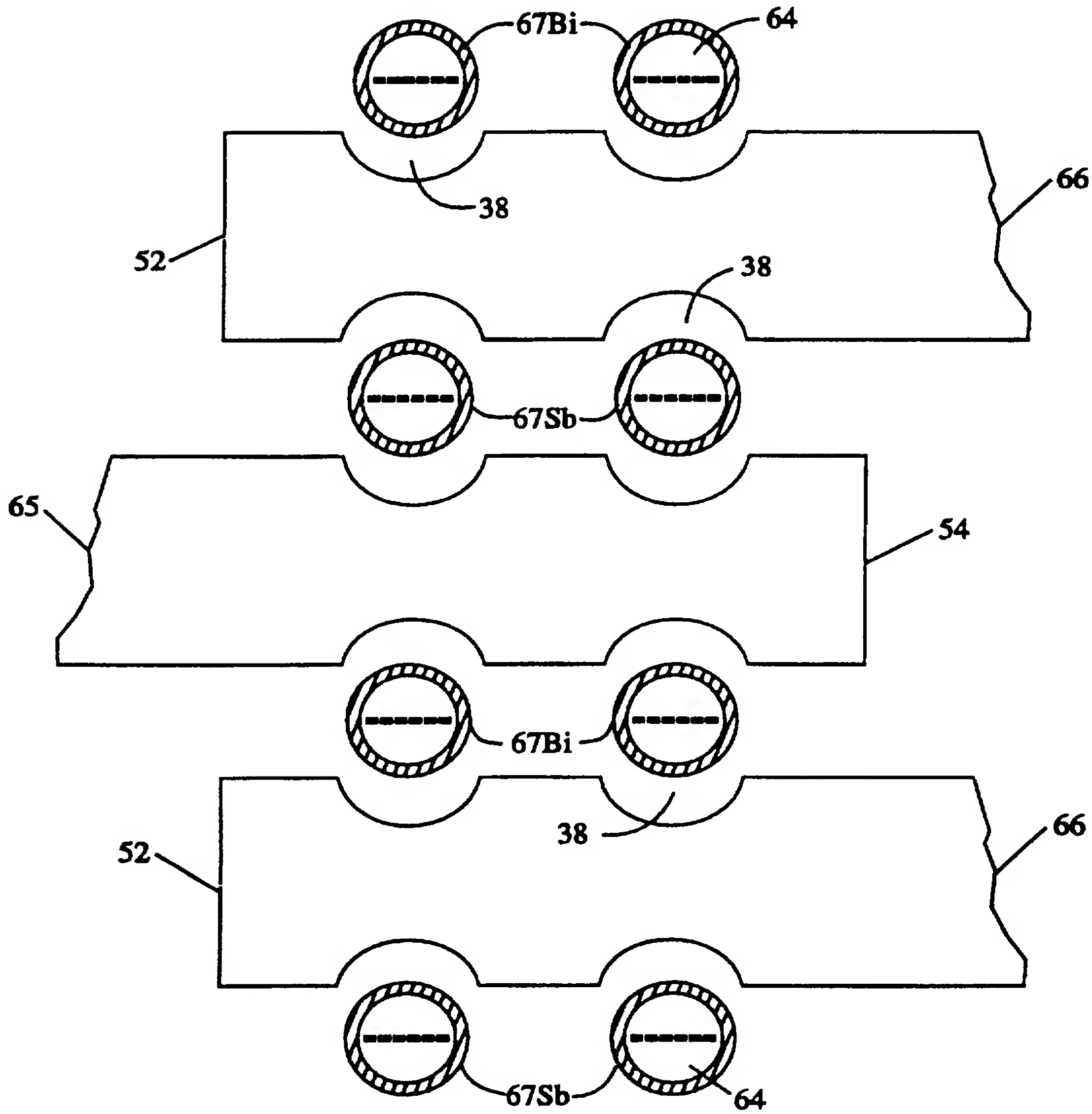

FIG. 38A

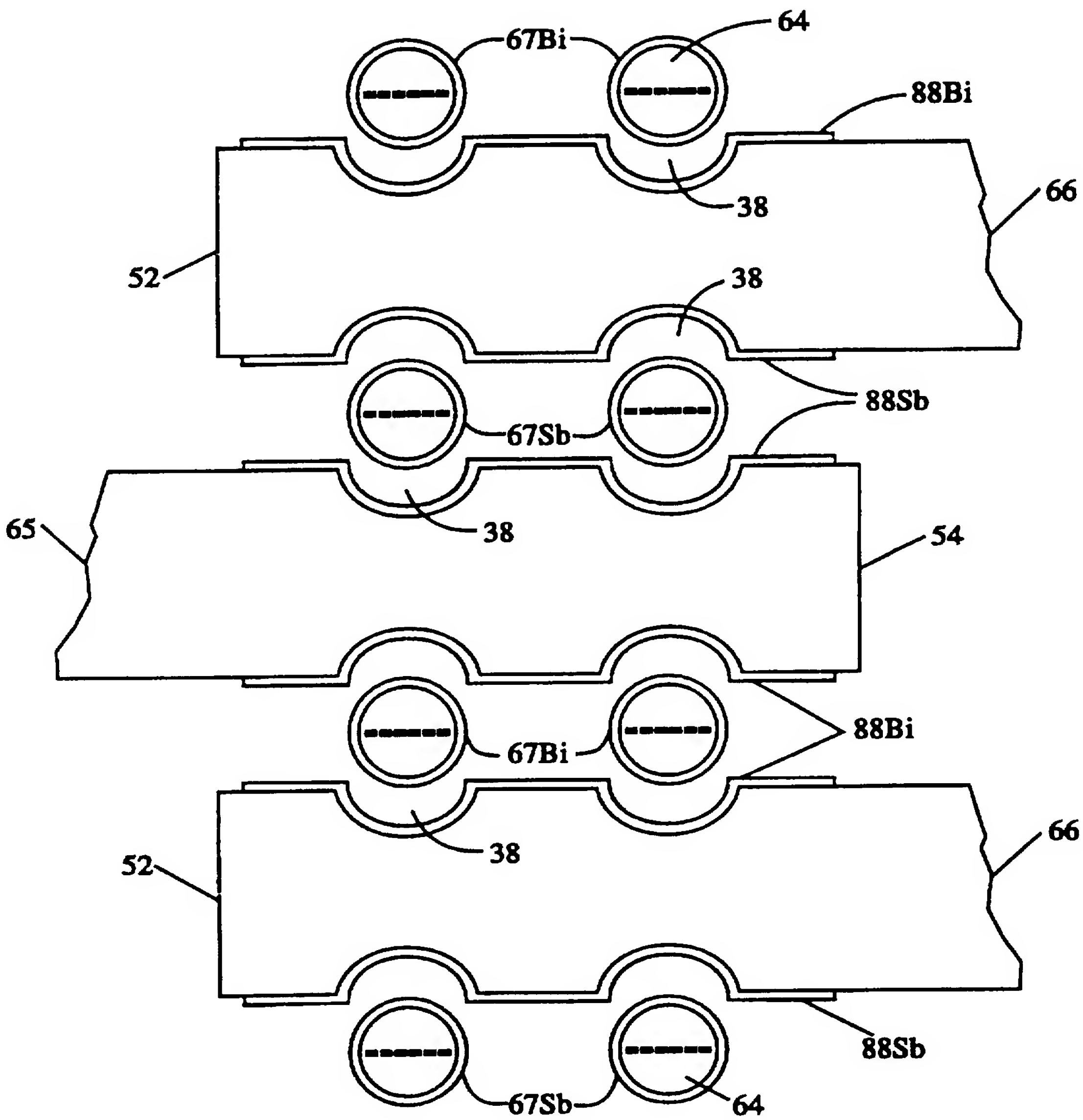
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FIG. 38B

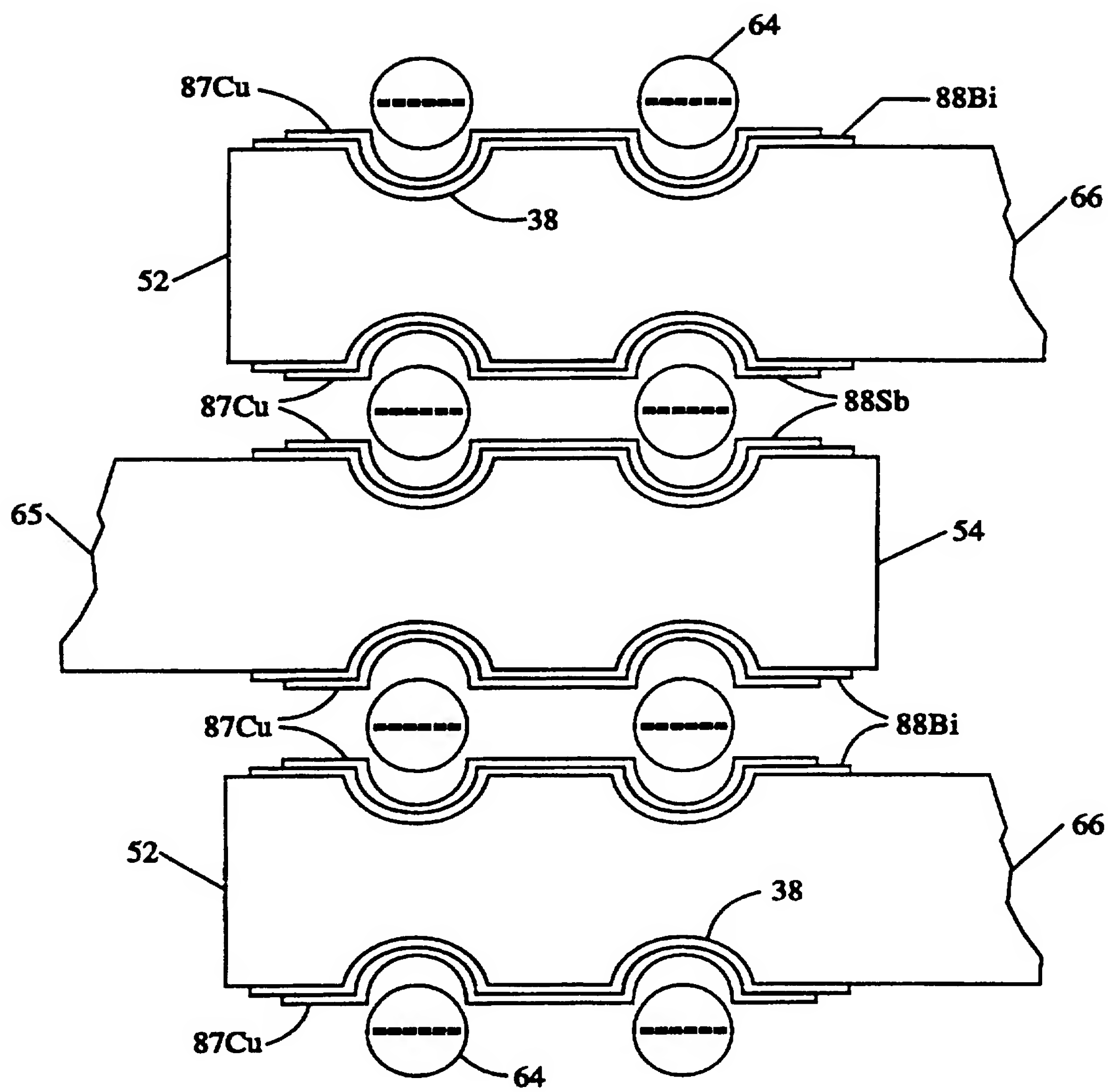
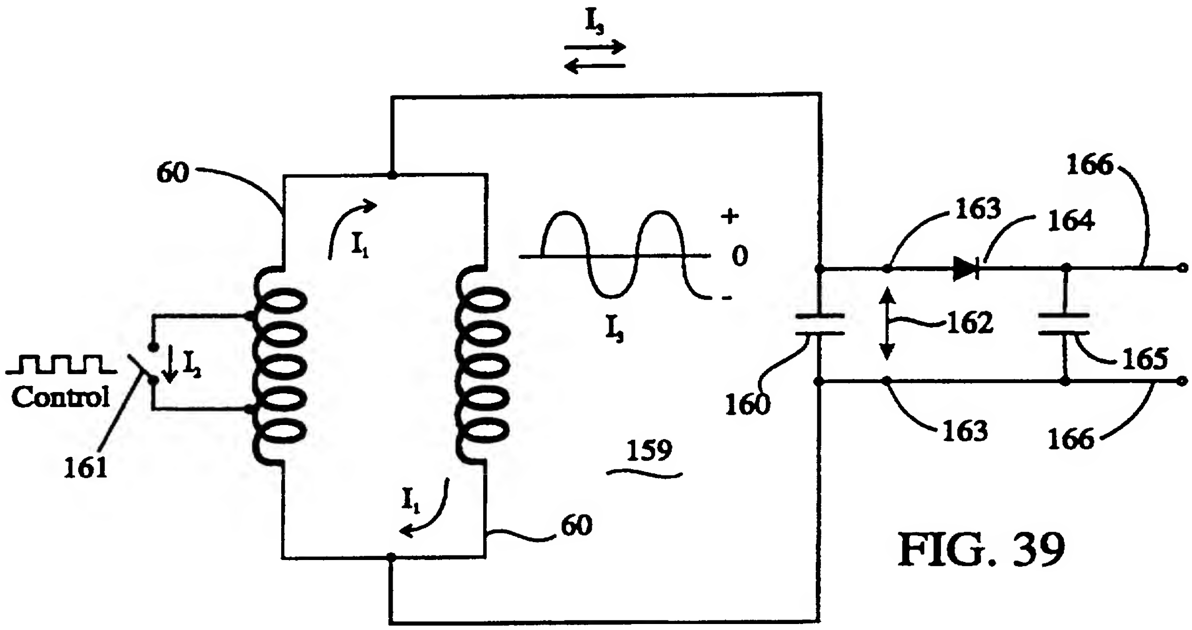


FIG. 38C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I1
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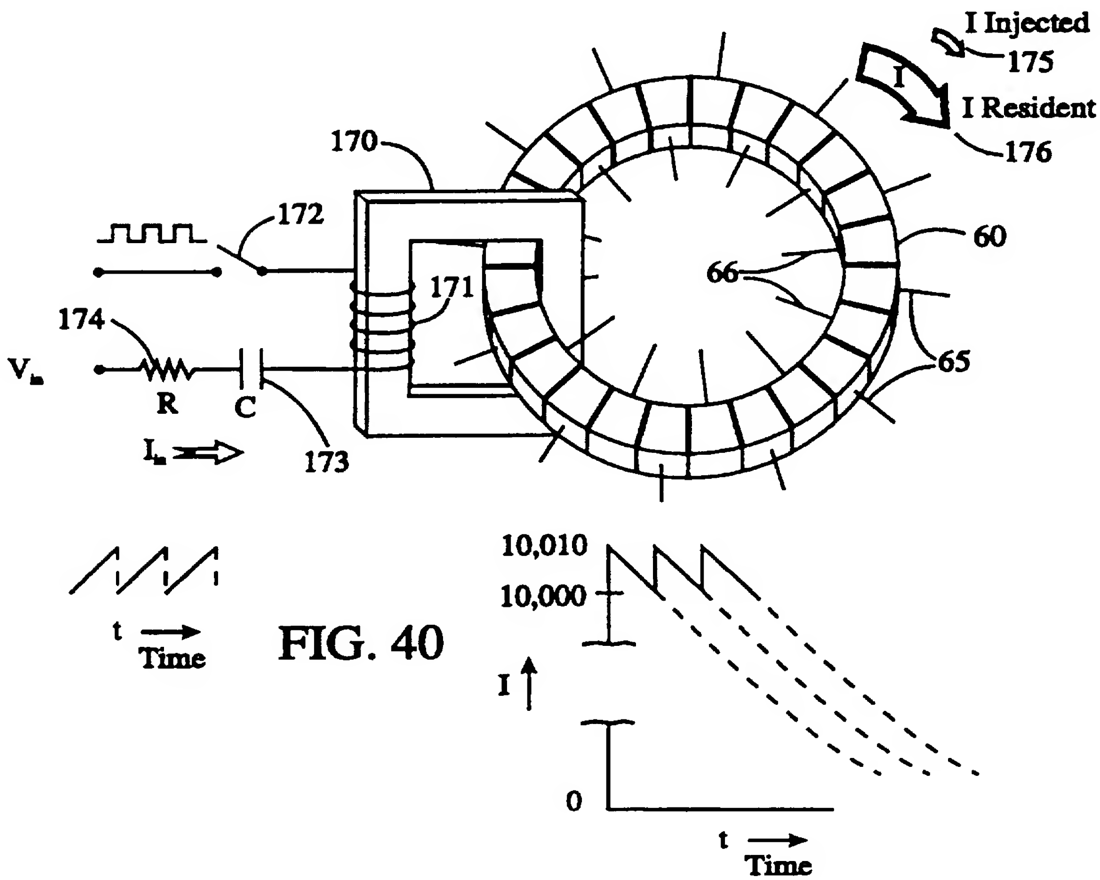
FIG. 39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Time
10,010
10,000
I
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t
Time

FIG. 40

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/07922

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : H01L 35/04, 35/06, 35/10, 35/18, 35/20
US CL :Please See Extra Sheet.
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 136/200, 202, 203, 204, 205, 208, 209, 210, 218, 220, 224, 230, 237, 238, 239, 240, 241, 242, 206, 207, 213, 214, 225, 228

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
NONE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X -- Y -- A	US 3,468,722 A (INTRATER et al) 23 September 1969, col. 3, line 19 through col. 6, line 49	1-2 ---- 15-19, 22-25, 27-29, 35, 39 -------- 3-14, 20-21, 26, 30-34, 36-38
Y	US 2,415,005 A (FINDLEY) 28 January 1947, col. 1, line 47 through col. 5, line 12	15, 17-19, 22, 24-25
Y	US 3,070,645 A (TRACHT) 25 December 1962, col. 1, line 33 through col. 2, line 41	16
Y	US 3,430,079 A (DANKO et al) 25 February 1969, col. 3, lines 1-13	23

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
29 AUGUST 1997	25 SEP 1997

Name and mailing address of the ISA/US	Authorized officer
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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 528,924 A (COX) 13 November 1894, pages 1-2	27-29
Y	US 5,376,184 A (ASPDEN) 27 December 1994, col. 5, line 44 through col. 27, line 40	35
Y -- A	US 5,441,576 A (BIERSCHENK et al) 15 August 1995, col. 2, line 40 through col. 4, line 68	39 --- 6-7, 9, 11-12
Y -- A	US 4,489,742 A (MOORE et al) 25 December 1984, col. 5, line 19 through col. 9, line 25	39 ---- 6-7, 9, 11-12
A	US 5,254,178 (YAMADA et al) 19 October 1993	1-39
A	US 3,181,304 A (BOKE) 04 May 1965	1-39
A	US 2,944,404 A (FRITTS) 12 July 1960	1-39
A	US 2,919,553 A (FRITTS) 05 January 1960	1-39

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US97/07922

A. CLASSIFICATION OF SUBJECT MATTER:
US CL :

136/200, 202, 203, 204, 205, 208, 209, 210, 218, 220, 224, 230, 237, 238, 239, 240, 241, 242